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# Environmental Radioactivity in Denmark in 1982

A. Aarkrog, L. Bøtter-Jensen, H. Dahlgaard,
Heinz Hansen, J. Lippert and S. P. Nielsen

Risø National Laboratory, DK-4000 Roskilde, Denmark
June 1983

Risø-R-487

# ENVIRONMENTAL RADIOACTIVITY IN DENMARK IN 1982

A. Aarkrog, L. Bøtter-Jensen, H. Dahlgaard, Heinz Hansen,
J. Lippert and S.P. Nielsen

Abstract. Strontium-90 was determined in samples from all over the country of precipitation, ground water, drinking water, sea water, dried milk, grain, bread, potatoes, vegetables, fruit, total diet, and human bone. Furthermore, $^{90}Sr$ was determined in local samples of air, rain water, marine sediments, grass, sea plants, fish and meat. Cesium-137 was determined in air, precipitation, sea water, sediments, milk, grain products, po-

(continued)

INIS-Descriptors: AIR; AMERICIUM ISOTOPES; AQUATIC ECOSYSTEMS; ATMOSPHERIC PRECIPITATIONS; BACKGROUND RADIATION; BARSEBAECK-1 REACTOR; BARSEBAECK-2 REACTOR; BONE TISSUES; CESIUM 137; COBALT 58; COBALT 60; DENMARK; DIET; DRINKING WATER; ENVIRONMENT; FALL-OUT DEPOSITS; FISHES; FOOD; FOOD CHAINS; GLOBAL FALLOUT; GROUND WATER; LOCAL FALLOUT; MAN; MANGANESE 54; MILK; PLANTS; PLUTONIUM ISOTOPES; RADIOACTIVITY; RINGHALS-1 REACTOR; RINGHALS-2 REACTOR; RINGHALS-3 REACTOR; RISOE NATIONAL LABORATORY; SEAWATER; SEA-WEEDS; SEDIMANTS; STRONTIUM 90; TRITIUM; ZINC 65.

UDC 614.73(489)

June 1983
Risø National Laboratory

tatoes, vegetables, fruit, total diet, sea plants, fish, and meat. Estimates of the mean contents of radiostrontium and radiocesium in the human diet in Denmark during 1982 are given. Tritium was determined in precipitation, fresh water and sea water. Plutonium and Americium were measured in sea water, sediments, sea plants and mussels. The γ-background was measured regularly by TLD, ionization chamber and on site γ-spectroscopy at locations around Risø, at ten of the State experimental farms along the coasts of the Great Belt and around Gylling Næs. The marine environments at Barsebäck and Ringhals were monitored for $^{137}Cs$ and corrosion products ($^{58}Co$, $^{60}Co$, $^{65}Zn$, $^{54}Mn$).

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## ABBREVIATIONS AND UNITS

J: joule: the unit of energy; 1 J = 1 Nm (= 0.239 cal)
Gy: gray: the unit of absorbed dose = 1 J $kg^{-1}$ (= 100 rad)
Sv: sievert: the unit of dose equivalent = 1 J $kg^{-1}$ (= 100 rem)
Bq: becquerel: the unit of radioactivity = 1 $s^{-1}$ (= 27 pCi)

cal: calorie = 4.186 J
rad: 0.01 Gy
rem: 0.01 Sv
Ci: curie: $3.7 \cdot 10^{10}$ Bq (= $2.22 \cdot 10^{12}$ dpm)

T: tera: $10^{12}$
G: giga: $10^{9}$
M: mega: $10^{6}$
m: milli: $10^{-3}$
μ: mikro: $10^{-6}$
n: nano: $10^{-9}$
p: pico: $10^{-12}$
f: femto: $10^{-15}$
a: atto: $10^{-18}$

cap: caput: (per individual)
TNT: trinitrotoluol; 1 Mt TNT: nuclear explosives equivalent to $10^{9}$ kg TNT.

cpm: counts per minute
dpm: disintegrations per minute
OR: observed ratio
CF: concentration factor
FP: fission products
μR: micro-roentgen, $10^{-6}$ roentgen
S.U.: pCi $^{90}Sr$ (g Ca)$^{-1}$
O.R.: observed ratio
M.U.: pCi $^{137}Cs$ (g K)$^{-1}$

V: vertebrae

m: male

f: female

nSr: natural (stable) Sr

eqv. mg KCl: equivalents mg KCl: activity as from 1 mg KCl (~ 0.88 dpm)

S.D.: standard deviation: $\sqrt{\frac{\Sigma(\bar{x}-x_i)^2}{(n-1)}}$

S.E.: standard error: $\sqrt{\frac{\Sigma(\bar{x}-x_i)^2}{n(n-1)}}$

U.C.L.: upper control level

L.C.L.: lower control level

S.S.D.: sum of squares of deviation: $\Sigma(\bar{x}-x_i)^2$

f: degrees of freedom

$s^2$: variance

$v^2$: ratio between the variance in question and the residual variance

P: probability fractile of the distribution in question

η: coefficient of variation, relative standard deviation

ANOVA: analysis of variance

A: relative standard deviation 20-33%

B: relative standard deviation >33%, such results are not considered significantly different from zero activity

B.D.L.: below detection limit

In the significance test the following symbols were used:

* : probably significant (P > 95%)

** : significant (P > 99%)

***: highly significant (P > 99.9%)

# 1. INTRODUCTION

## 1.1.

The present report is the twenty-sixth of a series of periodic reports (cf. ref. 1) dealing with measurements of radioactivity in Denmark. The organization of the material in the present report corresponds to that of last years report. However, we have included the measurements of tritium (earlier chapter 7) and of transuranic elements (earlier chapter 8) in chapters 4 and 5 under the relevant sample types. After the introduction and a chapter on organization and facilities there follows a chapter on environmental monitoring around nuclear facilities (Risø, Barsebäck and Ringhals). Chapter four deals with fallout nuclides in the abiotic environment, i.e. air, water and soil. Chapters five and six comprise fallout nuclides in the human diet and human tissues, respectively. Chapter seven is devoted to a general discussion of our environmental tritium studies. External radiation is treated in chapter eight. The names of the authors of each chapter appear at its head.

The Becquerel has replaced the Curie, however, in tables (mean values) and figures the Curie is shown for comparison. In the figures we have used the right-hand ordinate for Curie.

## 1.2.

The methods of radiochemical analysis[2-4] and the statistical treatment of the results[5,12] are still based on the principles established in previous reports[1].

1.3.

The detailed tables of the environmental monitoring programme for Risø National Laboratory appear in the two semiannual reports: Radioactivity in the Risø district January-June 1982 and July-December 1982.

1.4.

The report contains no information on sample collection and analysis except in cases where these procedures have been altered.

1.5.

In 1982 the personnel of the Environmental Control Section of the Health Physics Department consisted of two chemists, one biologist, one statistician, eight laboratory technicians, two sample collectors, and two laboratory assistants. The Section for Electronics Development continued to give assistance with the maintenance of counting equipment, with the interpretation of $\gamma$-spectra and with data treatment. The programme (cf. 2) used in the calculations of $^{90}Sr$ and the $\gamma$-analysis, as well as the programme for data treatment, were developed by this Section.

1.6.

The composition of the average Danish diet used in this report is identical with that proposed in 1962 by the late Professor E. Hoff-Jørgensen, Ph.D.

## 2. FACILITIES[1,6,7,8]

By J. Lippert

### 2.1. Detectors

The activity of the samples is measured as follows:

Alpha ($^{239}Pu$, $^{241}Am$): 20 solid-state surface barrier detectors connected to four multichannel analyzers (64 channels per detector) and another two for total alpha counting.

Beta ($^{90}Y$ mainly): Six "multidetector"-systems each containing 5 sample counters and a common anticoincidence shield are now put into regular use. This type of detector has replaced the mechanical sample changers previously used.

Gamma (natural and fallout isotopes): 4 Ge(Li) detectors in 10 cm lead shields and connected to a 8192-channel analyzer with four-input facility. One further Ge(Li) detector mounted on a tripod and a 4096-channel analyzer are used for field measurements, and a 8" × 4" NaI(Tl) in an underground shielded room is used for whole-body counting. The Ge(Li) detectors have an efficiency of $\geq$ 20% (relative to 3" × 3" NaI(Tl)).

### 2.2. Data treatment

Measured spectra are transferred to a Burroughs B6700 computer for evaluation.

A program system STATDATA[16] is developed for registration and treatment of environmental measurements including multichannel analyzer spectra. To date, approximately 60 000 sets of results have been registered covering the period from 1957.

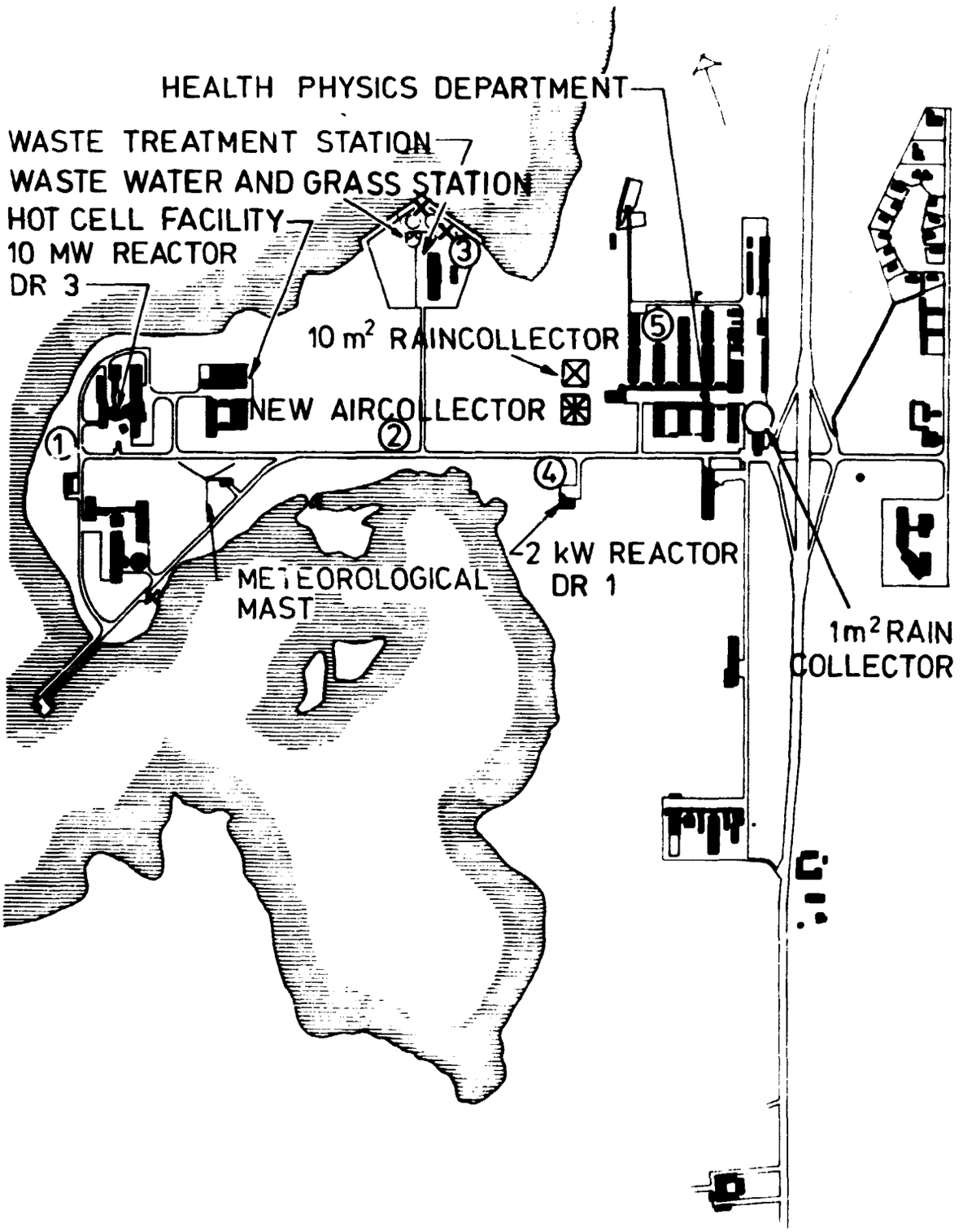


Fig. 3.1.1. Sampling locations at Risø National Laboratory. 1-5: locations for rain bottles (0.03 $m^2$ each), ion-exchange columns (0.06 $m^2$ each) and grass samples.

# 3. ENVIRONMENTAL MONITORING AT RISØ, BARSEBÄCK AND RINGHALS IN 1982

by H. Dahlgaard

## 3.1 Environmental monitoring at Risø

From the two semiannual reports: Radioactivity in the Risø district January-June 1982 and July-December 1982 the results of the environmental monitoring at Risø are presented. The reports are available from the Risø Library.

The various anthropogenic radionuclides measured outside the Risø area came from non-Risø sources, preferentially from global fallout.

## 3.2. Marine environmental monitoring at Barsebäck and Ringhals

The radiological monitoring of the marine environment around the two nuclear power plants at Barsebäck and Ringhals in Sweden[1] was continued in 1982.

Figures 3.2.1.1 and 3.2.1.2 show the sampling locations.

This programme is partly sponsored by the Nordic Liason Committee for Atomic Energy (Nordisk kontaktorgan for atomenergi) as part of a co-operative activity together with the Department of Radiotion Physics, University of Lund, Sweden.

### 3.2.1. γ-emitting radionuclides in brown algae

Tables 3.2.1.1, 3.2.1.2, and 3.2.1.3 show the radionuclide concentrations found by γ-spectrometric analysis in brown algae sampled near Barsebäck and Ringhals in 1982. Previously, all data in this chapter have been reported on the basis of fresh weights. However, as the water contents of seaweed may vary,

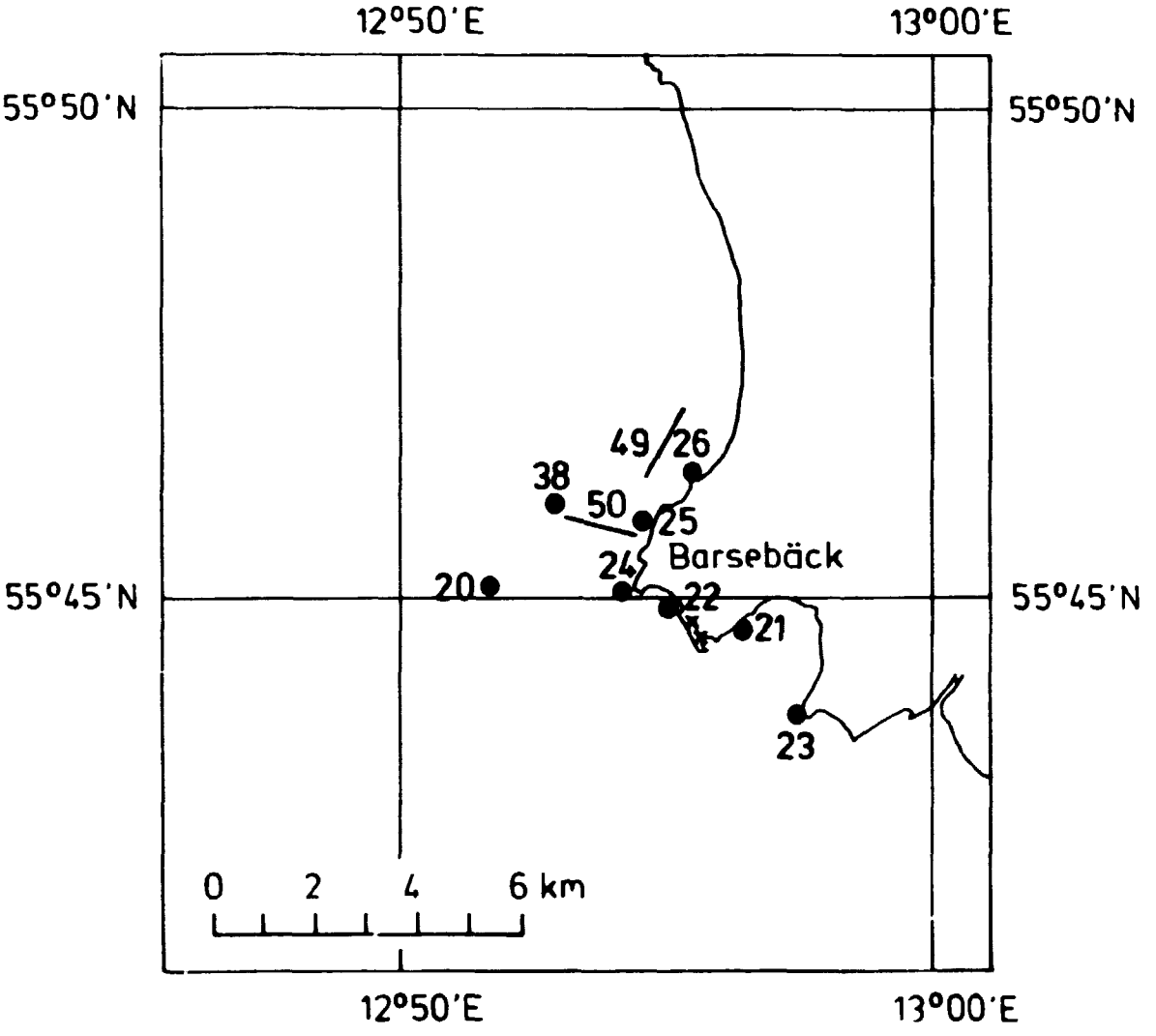


Fig. 3.2.1.1. Sampling locations at Barsebäck. 49 and 50 indicate fishing tracks.

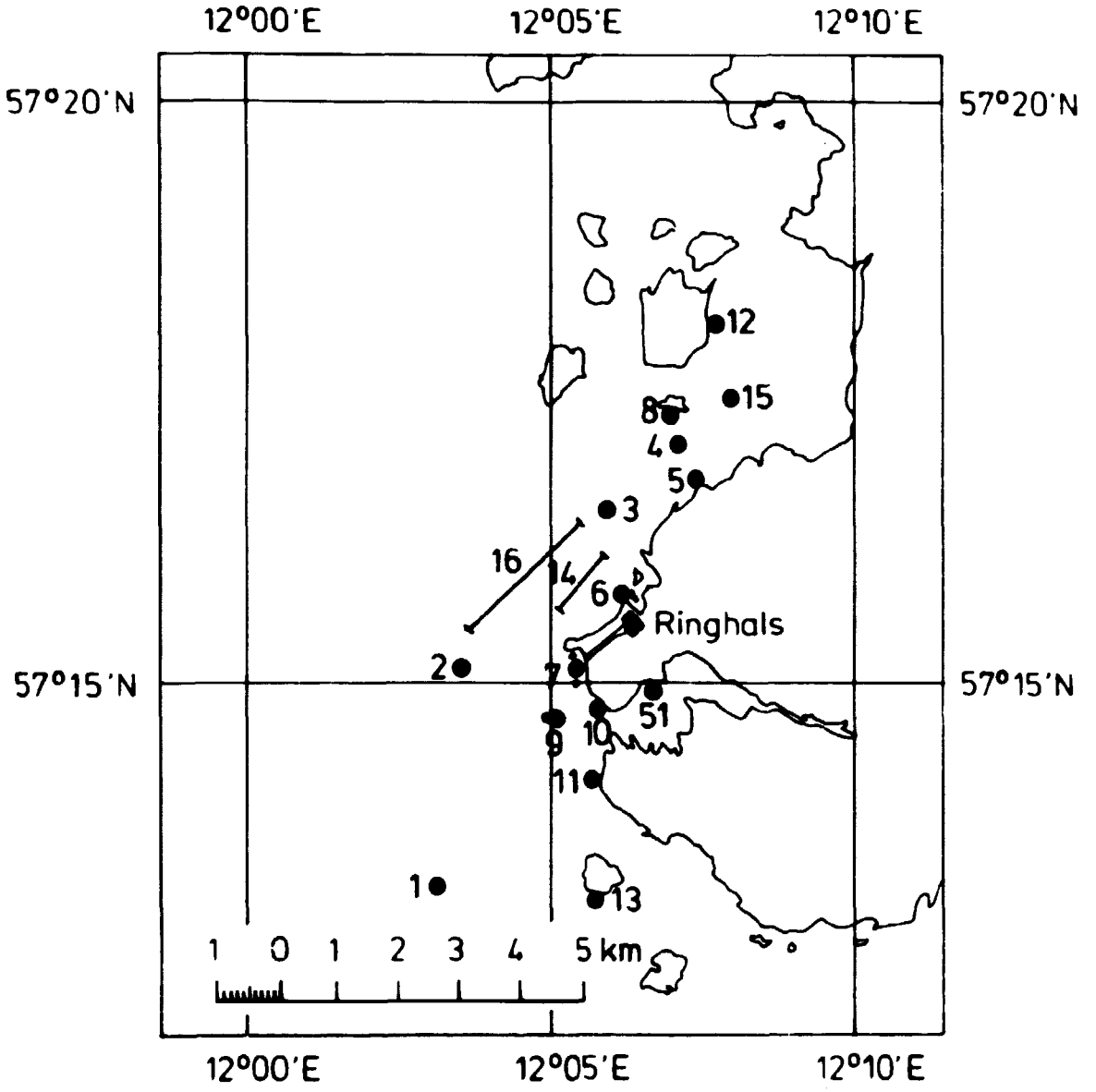


Fig. 3.2.1.2. Sampling locations at Ringhals. 14 and 16 indicate fishing tracks.

Table 3.2.1.1. Gamma-emitting radionuclides in Fucus vesiculosus (Fu.ve.), and Zostera marina (Zo.ma.) collected at Barsebäck in 1982 (Unit: Bq $kg^{-1}$ dry weight)

| Date of sampling | 20 April | | 24 June | | | | 16 September | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Station No.** | 21* | 23* | 25 | 26 | 21* | 23* | 24 | 25 | 25 | 26 |
| Weight fresh/dry | 6.01 | 6.20 | 5.19 | 4.91 | 4.70 | 5.32 | 4.21 | 4.97 | 5.21 | 5.19 |
| Species | Fu.ve. | Fu.ve. | Fu.ve. | Zo.ma. | Fu.ve. | Fu.ve. | Fu.ve. | Fu.ve. | Zo.ma. | Fu.ve. |
| Distance from outlet in km | 1.5 | 2.8 | 2.9 | 4.0 | 1.5 | 2.8 | 1.4 | 2.9 | 2.9 | 4.0 |
| $^{54}Mn$ | 6.8 | 1.75 | 16.6 | 3.8 | 6.2 | 3.3 | 84 | 27 | 32 | 15.4 |
| $^{57}Co$ | | | 0.7 A | | | | | | | |
| $^{58}Co$ | 7.5 | 1.36 | 7.5 | 1.2 B | 3.4 | 1.2 B | 96 | 29 | 40 | 12.6 |
| $^{60}Co$ | 260 | 56 | 570 | 53 | 177 | 66 | 3000 | 380 | 350 | 181 |
| $^{65}Zn$ | 36 | 6.8 | 62 | 5.8 | 17.1 | 4.8 | 240 | 31 | 42 | 14.0 |
| $^{95}Zr$ | | 1.6 A | 14.0 | | | | | | | |
| $^{95}Nb$ | 1.5 B | 1.53 | | | | | | | | |
| $^{131}I$ | 12.3 | 3.2 | | | | | | | | |
| $^{134}Cs$ | | | | | | | | 2.0 | | |
| $^{137}Cs$ | 11.9 | 16.2 | | 3.0 | 11.9 | 13.7 | 12.6 | 11.4 | 3.0 B | 12.9 |
| $^{144}Ce$ | | 3.0 A | | | | 4.2 A | | | | |
| $^{226}Ra$ | 19.2 | 15.2 | 27 | 6.0 | 17.7 | 13.8 | 16.7 | 13.0 | | 11.3 |
| $^{228}Ra$ | 22 | 19.3 | 26 | 8.2 | 29 | 26 | 22 A | | | 24 |
| $^{228}Th$ | 6.6 | 8.8 | 4.7 | 6.7 | 5.6 | 7.7 | | | | 14 A |

* Locations south of the outlet; the other locations were situated north of the outlet.

**Cf. Fig. 3.2.1.

Table 3.2.1.2. Gamma-emitting radionuclides in Fucus vesiculosus (Fu.ve.) and Fucus serratus (Fu.se.) collected at Ringhals July 7-8, 1982. (Unit: Bq $kg^{-1}$ dry weight)

| Station No.** | 7 | 6 | 5 | 8 | 12 | 9* | 11* | 13* |
|---|---|---|---|---|---|---|---|---|
| Weight fresh/dry | 5.08 | 5.27 | 4.77 | 7.07 | 4.65 | 4.20 | 4.71 | 4.52 |
| Species | Fu.ve. | Fu.ve. | Fu.ve. | Fu.ve. | Fu.ve. | Fu.se. | Fu.ve. | Fu.se. |
| Distance from outlet in km | 0.2 | 1.9 | 4.1 | 4.8 | 6.3 | 1.1 | 1.9 | 4.1 |
| $^{54}Mn$ | 15.0 | 3.9 | 1.98 | 0.9 B | 1.85 | 4.4 | 1.67 | 0.93 |
| $^{57}Co$ | 0.5 B | | | | | | | |
| $^{58}Co$ | 73 | 17.1 | 15.6 | 6.9 | 10.6 | 41 | 6.7 | 4.8 |
| $^{60}Co$ | 116 | 32 | 18.4 | 9.5 | 15.9 | 41 | 19.8 | 10.7 |
| $^{65}Zn$ | 310 | 109 | 43 | 19.8 | 17.6 | 107 | 91 | 43 |
| $^{95}Nb$ | | | | | | | | 0.6 A |
| $^{110m}Ag$ | 11.9 | 2.1 | 1.25 | | | 2.7 | 1.98 | 0.4 B |
| $^{134}Cs$ | 1.4 A | | | 0.6 A | 0.43 | 0.30 | 0.50 | 0.28 |
| $^{137}Cs$ | 12.4 | 11.2 | 9.8 | 8.7 | 18.0 | 10.5 | 14.5 | 12.2 |
| $^{144}Ce$ | | | | | 4.6 | | | |
| $^{226}Ra$ | 8.2 | 10.0 | 6.6 | 9.0 | 9.4 | 8.2 | 6.7 | 7.2 |
| $^{228}Ra$ | 14.3 | 16.2 | 17.2 | 12.0 | 18.7 | 12.2 | 15.0 | 16.9 |
| $^{228}Th$ | 3.8 | 4.4 | 4.0 | 3.6 | 5.6 | 2.1 A | 2.7 | 3.3 |

* Locations south of the outlet; the other locations were situated north of the outlet.

**Cf. Fig. 3.2.2.

e.g. due to differences in handling, dry weights will now be used. Results in tables including earlier years have been recalculated individually. For comparison with other data, the mean values of the ratios fresh weight/dry weight obtained 1977-1982 can be used. For Fucus vesiculosus and Fucus serratus from Ringhals these are 4.43±0.10 (S.E., n = 43) and 3.94±0.06 (S.E., n = 23), respectively, and for Fucus vesiculosus from Barsebäck the ratio is 5.02±0.14 (S.E., n = 36). The 3 ratios are significantly different.

Table 3.2.1.3. Gamma-emitting radionuclides in Fucus vesiculosus (Fu.ve.) and Fucus serratus (Fu.se.) collected at Ringhals October 23, 1982. (Unit: Bq $kg^{-1}$ dry weight)

| Station No.** | 7 | 6 | 5 | 5 | 8 | 8 | 9* |
|---|---|---|---|---|---|---|---|
| Weight fresh/dry | 3.81 | 3.92 | 4.46 | 3.74 | 4.09 | 3.75 | 4.55 |
| Species | Fu.ve. | Fu.ve. | Fu.ve. | Fu.se. | Fu.ve. | Fu.se. | Fu.ve. |
| Distance from outlet in km | 0.2 | 1.9 | 4.1 | 4.1 | 4.8 | 4.8 | 1.1 |
| $^{54}Mn$ | 13.5 | 2.7 | 1.78 | 1.31 | 1.0 A | 1.51 | 2.4 |
| $^{58}Co$ | 33 | 4.0 | 4.0 | 7.2 | 3.2 | 5.6 | 12.1 |
| $^{60}Co$ | 210 | 38 | 18.3 | 29 | 14.7 | 25 | 39 |
| $^{65}Zn$ | 500 | 110 | 56 | 64 | 37 | 59 | 118 |
| $^{110m}Ag$ | 11.8 | 2.5 | 1.66 | 1.41 | 1.0 A | 1.0 A | 7.1 |
| $^{134}Cs$ | 1.1 A | 0.4 B | | | 0.3 B | 0.5 B | 0.6 B |
| $^{137}Cs$ | 10.8 | 8.0 | 8.8 | 7.2 | 8.7 | 7.9 | 9.4 |
| $^{226}Ra$ | 3.3 | 2.3 | 3.7 | 4.8 | 10.0 | 10.4 | 3.2 |
| $^{228}Ra$ | 15.4 | 14.6 | 13.7 | 16.3 | 16.0 | 15.5 | 11.2 |
| $^{228}Th$ | 16.4 | 2.6 | 2.5 | 2.3 | 4.3 | 5.5 | 11 B |

* Locations south of the outlet; the other locations were situated north of the outlet.

**Cf. Fig. 3.2.2.

Figures 3.2.1.3 and 3.2.1.4 show the concentration of $^{60}Co$ in seaweed from Barsebäck and Ringhals since 1977.

Table 3.2.1.5 shows a comparison of the 3 fucoids Fucus vesiculosus, Fucus serratus and Ascophyllum nodosum. The levels of significance of differences from unity are indicated. It is noted that these results indicate that Fucus serratus on average contained ~ 40% more $^{60}Co$ than Fucus vesiculosus. The ratio $^{60}Co/^{58}Co$ tends to increase in the order Fucus vesiculosus < Fucus serratus < Ascophyllum nodosum. This indicates that the "integration time" and perhaps also the average age of the biomass for the 3 species rises in the same manner.

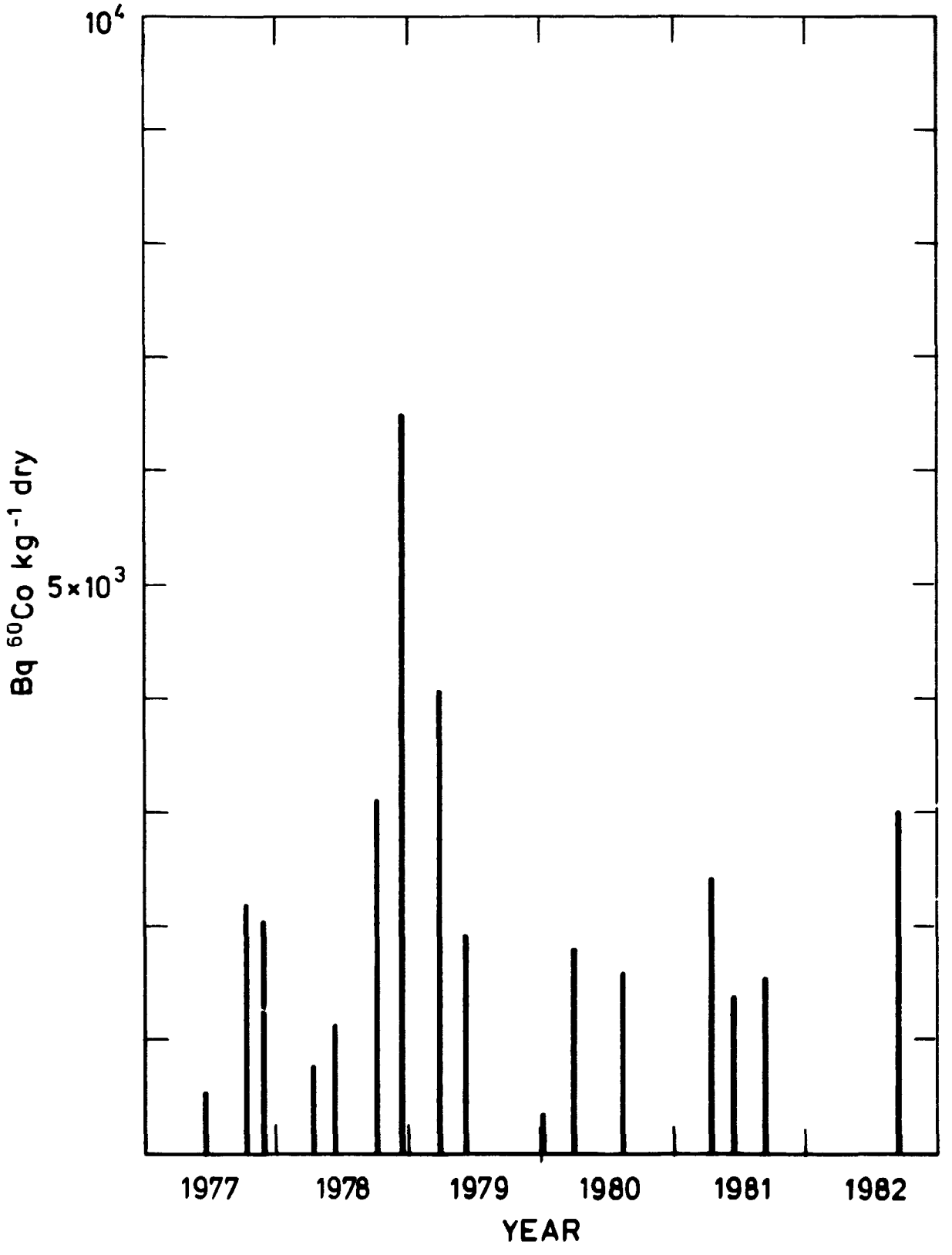


Fig. 3.2.1.3. Cobalt-60 in Fucus vesiculosus collected at Barsebäck, location 24, 1977-1982. (Unit: Bq kg$^{-1}$ dry weight).

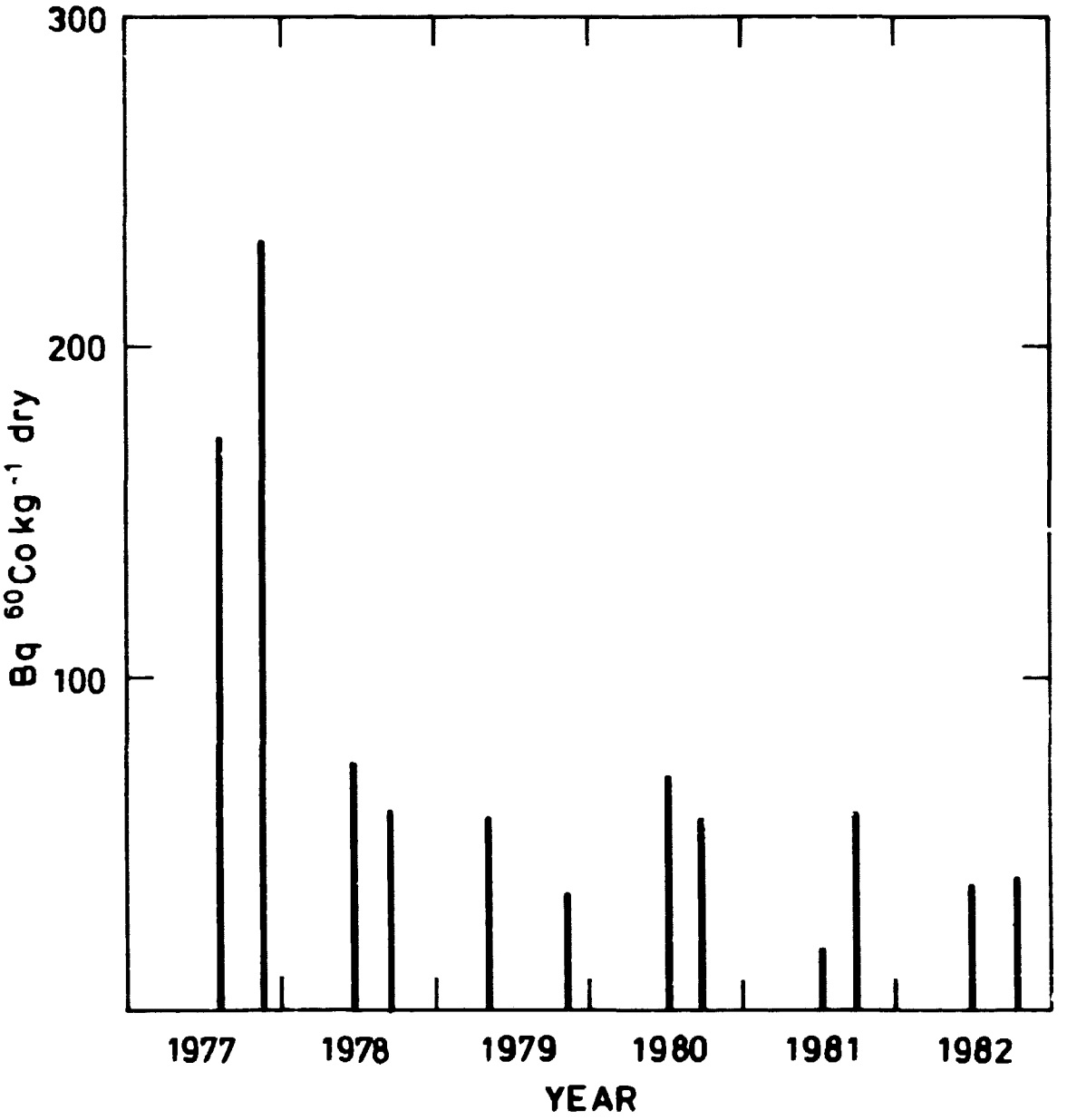


Fig. 3.2.1.4. Cobalt-60 in Fucus vesiculosus and Fucus serratus collected at Ringhals, locations 6 and 9, 1977-1982. (Mean of all data) (Unit: Bq kg$^{-1}$ dry weight).

Table 3.2.1.5. Ratios of activity concentrations on dry weight basis in Fucus vesiculosus (Fu.ve.), Fucus serratus (Fu.se.) and Ascophyllum nodosum (As.no.) collected at Ringhals 1978-1982

| Isotope | Fu.ve./Fu.se. | Fu.ve./As.no. |
|---|---|---|
| $^{60}Co$ | 0.71*** ±0.056 (n=8) | 1.3 ±0.34 (n=5) |
| $^{58}Co$ | 0.81* ±0.071 (n=7) | 3.1* ±0.51 (n=5) |
| $^{54}Mn$ | 1.11 ±0.136 (n=6) | 3.9* ±0.51 (n=3) |
| $^{65}Zn$ | 0.83 ±0.141 (n=8) | 1.7 ±0.42 (n=5) |
| $^{110m}Ag$ | 1.19 ±0.158 (n=5) | 1.2 ±0.25 (n=4) |
| $^{137}Cs$ | 1.13 ±0.071 (n=7) | 1.4* ±0.06 (n=3) |
| $^{131}I$ | 0.94 (n=1) | 1.2 (n=1) |
| $^{95}Zr$ | 0.89 (n=1) | |

The error term was 1 S.E.

Tables 3.2.1.6-3.2.1.7 report transfer factors calculated as

$$TF = \frac{A_i}{\frac{1}{m}\sum^{m} D_j} \quad , \left(\frac{Bq\ kg^{-1}}{GBq\ month^{-1}}\right)$$

Where $A_i$ is the activity of the sample collected in month i (Bq $kg^{-1}$ dry weight), $D_j$ is the discharge during month j (Bq $month^{-1}$) and m is the number of months in the calculation. Here m is chosen as 12, i.e. the transfer factors are based on the mean discharge rate during the 12 months preceding the sampling. Monthly discharges are from reference 36.

In Tables 3.2.1.6 and 3.2.1.7 transfer factors, TF, from Barsebäck and Ringhals from 1982, and mean values from 1977-1982 are reported. As the monthly discharges are very different the

Table 3.2.1.6. Transfer factor, TF, without decay-correction. Fucus vesiculosus collected at Barsebäck, location 24, 1.4 km north of the outlet

| Isotope | Sampling date | Discharge the preceding 12 months | | TF Bq kg$^{-1}$ dry weight | |
|---|---|---|---|---|---|
| | | GBq month$^{-1}$ | rel. S.E.% | GBq month$^{-1}$ | |
| $^{60}$Co | 16/9-82 | 6.6 | 76 | 450 | (n = 1) |
| $^{60}$Co mean: | 1977-1982 | | | 660±88 | (n = 16) |
| $^{58}$Co | 16/9-82 | 0.48 | 102 | 200 | (n = 1) |
| $^{58}$Co mean: | 1977-1982 | | | 270±52 | (n = 16) |
| $^{54}$Mn | 16/9-82 | 0.27 | 73 | 310 | (n = 1) |
| $^{54}$Mn mean: | 1977-1982 | | | 420±48 | (n = 16) |
| $^{65}$Zn | 16/9-82 | 0.83 | 91 | 290 | (n = 1) |
| $^{65}$Zn mean: | 1977-1982 | | | 570±98 | (n = 16) |
| $^{110m}$Ag mean: | 1977-1981 | | | 87±15.8 | (n = 10) |
| $^{51}$Cr mean: | 1977-1981 | | | 49±17.5 | (n = 4) |

The error term was ±1 S.E.

TF-values will vary even if the plants accumulate the same fraction of the discharged nuclides throughout the year. Differences in growth and perhaps in temperature also contribute to the variation. The fairly good reproducibility of the TF-value for most nuclides from both Barsebäck and Ringhals is therefore remarkable. These TF-values, calculated on the basis of controlled discharges during several years, can be used to estimate the magnitude of an uncontrolled release on the basis of a few Fucus samples. A bias may occur due to differences in chemical speciation. However, this will not be serious as bio-indicator data reports the biologically available fraction and thereby the potential transport to man.

Table 3.2.1.7. Transfer factor, TF, without decay-correction. Fucus vesiculosus and Fucus serratus (from Tables 3.2.1.2 and 3.2.1.3) collected at Ringhals, location 6, 1.9 km north of the outlet and location 9, 1.1 km south of the outlet

| Isotope | Sampling date | Discharge the preceding 12 months | | TF = $\frac{\text{Bq kg}^{-1}\text{ dry weight}}{\text{GBq month}^{-1}}$ | |
|---|---|---|---|---|---|
| | | GBq month$^{-1}$ | rel. S.D.% | Location 6 | Location 9 |
| $^{60}$Co | 7/7 | 3.88 | 61 | 8.2 | 10.5 |
| " | 23/10 | 2.85 | 46 | 13.3 | 13.8 |
| $^{60}$Co mean: | 1982 | | | 10.8±2.58(n=2) | 12.2±1.65(n=2) |
| | 1977-1982 | | | 11.2±2.03(n=12) | 13.4±2.45(n=12) |
| $^{58}$Co | 7/7 | 2.01 | 74 | 8.5 | 20.5 |
| " | 23/10 | 1.44 | 68 | 2.7 | 8.4 |
| $^{58}$Co mean: | 1982 | | | 5.6±2.89(n=2) | 14.4±6.02(n=2) |
| | 1977-1982 | | | 5.6±0.64(n=12) | 12.5±2.07(n=12) |
| $^{54}$Mn | 7/7 | 0.29 | 70 | 13.7 | 15.2 |
| " | 23/10 | 0.198 | 50 | 13.5 | 12.2 |
| $^{54}$Mn mean: | 1982 | | | 13.6±0.13(n=2) | 13.7±1.51(n=2) |
| | 1977-1982 | | | 13.0±2.16(n=12) | 12.1±1.26(n=12) |
| $^{65}$Zn | 7/7 | 7.65 | 130 | 14.2 | 14.0 |
| " | 23/10 | 2.21 | 67 | 50.0 | 53.6 |
| $^{65}$Zn mean: | 1982 | | | 32.1±17.89(n=2) | 33.8±19.79(n=2) |
| | 1977-1982 | | | 45.1±12.00(n=12) | 73.0±16.91(n=12) |
| $^{110m}$Ag | 7/7 | 0.083 | 101 | 24.9 | 32.8 |
| " | 23/10 | 0.055 | 74 | 45.2 | 128.4 |
| $^{110m}$Ag mean: | 1982 | | | 35.0±10.2(n=2) | 80.6±47.79(n=2) |
| | 1977-1982 | | | 65.3±25.3(n=10) | 144.5±39.22(n=11) |
| $^{51}$Cr mean: | 1978 | | | 1.13 (n=1) | |

The error term was ±1 S.E.

As discussed earlier[1,32], the TF-values are higher at Barsebäck than at Ringhals. As furthermore ratios between radionuclides differs, a hydrodynamical explanation will not be sufficient.

### 3.2.2. γ-emitting radionuclides in benthic invertebrates

Tables 3.2.2.1 and 3.2.2.2 show results of the γ-countings on benthic animals from Barsebäck and Ringhals in 1982, and in Tables 3.2.2.3 and 3.2.2.4 these results have been compared with identical Fucus samples, when available. As for the seaweeds (cf. Chapter 3.2.1), the results for benthic animals are now reported on the basis of dry weights. The dose commitment to a hypothetical critical individual consuming 20 kg Mytilus edulis soft parts (fresh weight) yearly would be approximately 11 μSv $y^{-1}$ based on the sample from location 24 in Table 3.2.2.1. These mussels are, however, not edible as

Table 3.2.2.1. Gamma-emitting radionuclides in benthic animals collected at Barsebäck in 1982. (Unit: Bq $kg^{-1}$ dry weight)

| Species | Mytilus edulis (soft part) | Mytilus edulis (soft part) | Macoma balthica (soft part) | Macoma balthica (hard part) |
|---|---|---|---|---|
| Date | 20 April | 21 April | 21 April | 21 April |
| Station No.* | 24 | 49 | 49 | 49 |
| Weight fresh/dry | 6.67 | 9.62 | 5.38 | 1.17 |
| Distance from outlet in km | 1.4 | ~ 4 | ~ 4 | ~ 4 |
| Depth in m | 0.5 | 7 | 7 | 7 |
| $^{54}Mn$ | 5.6 A | | | |
| $^{58}Co$ | 11.8 | | | |
| $^{60}Co$ | 450 | 27 | 80 | 3.0 |
| $^{65}Zn$ | 300 | 14.4 | 47 | |
| $^{137}Cs$ | 3.5 A | 4.4 | 8.2 B | |
| $^{141}Ce$ | | | 17 B | 3.6 |
| $^{226}Ra$ | | 3.4 | 47 A | 6.6 A |
| $^{228}Ra$ | | 4.0 B | 63 A | 12 A |
| $^{228}Th$ | | 3.7 A | | |

*Cf. Fig. 3.2.1.1.

Table 3.2.2.2. Gamma-emitting radionuclides in benthic animals collected at Ringhals in 1982. (Unit: Bq $kg^{-1}$ dry weight)

| Species | Mytilus edulis (soft part) | Cyprina islandica (soft part) | Buccinum undatum (soft part) | Starfish (total) | Cancer pagurus (total) | Eupagurus bernhardus (total) | Alcyonium digitatum (total) | Buccinum undatum (soft part) | Cyprina islandica (soft part) | Sea urchin (total) |
|---|---|---|---|---|---|---|---|---|---|---|
| Date | 7 July | 8 July | 9 July | 9 July | 9 July | 24 October | 24 October | 24 October | 24 October | 24 october |
| Station No.* | 12 | 16 | 14 | 14 | 14 | 16 | 16 | 16 | 16 | 16 |
| Weight fresh/dry | 7.80 | 7.92 | 4.99 | 3.46 | 2.78 | 3.35 | 7.44 | 4.48 | 3.72 | 1.87 |
| Distance from outlet in km | 6.3 | ~ 2 | ~ 2 | ~ 2 | ~ 2 | ~ 2 | ~ 2 | ~ 2 | ~ 2 | ~ 2 |
| Depth in m | 0.5 | 20 | 16 | 16 | 16 | 22 | 22 | 22 | 22 | 22 |
| $^{54}Mn$ | | | | | 0.17 | | | | | |
| $^{58}Co$ | 2.9 | | | | | | | | | |
| $^{60}Co$ | 5.0 | 3.3 | 3.4 | 0.4 A | 0.52 | | | | | 10.2 |
| $^{65}Zn$ | 30 | 6.3 | 19.8 | 8.2 | 1.22 | | 5.3 B | | | 5 B |
| $^{110m}Ag$ | 0.90 | 1.63 | | 0.5 A | 0.26 | | | | | |
| $^{125}Sb$ | | | | | 0.5 A | B.D.L. | | B.D.L. | B.D.L. | |
| $^{134}Cs$ | | | | | 0.096 | | | | | |
| $^{137}Cs$ | 4.6 | 4.5 | 4.3 | 0.83 | 2.6 | | 4.6 | | | 10 |
| $^{144}Ce$ | 2.4 A | | | | | | | | | |
| $^{226}Ra$ | 3.8 | 16.3 | | | 1.81 | | | | | 14.9 |
| $^{228}Ra$ | 5.1 | 5.3 | | | 5.0 | | | | | 16.4 |
| $^{228}Th$ | 2.0 A | 4.6 | | | 2.2 | | | | | 21 |

*Cf. Fig. 3.2.1.2.

Table 3.2.2.3. Activity ratios on dry weight basis, Mytilus edulis soft part to Fucus vesiculosus collected at Barsebäck in 1980-1981

| Location | $^{60}Co$ | $^{58}Co$ | $^{65}Zn$ | $^{137}Cs$ | $^{110m}Ag$ | $^{54}Mn$ | $^{95}Zr$ | $^{144}Ce$ |
|---|---|---|---|---|---|---|---|---|
| Mean 1980-1981 | 0.174 | 0.313 | 0.93 | 0.351 | 3.38 | 0.072 | 0.297 | 0.82 |
| S.E. | 0.051 | 0.167 | 0.34 | 0.059 | | 0.006 | | |
| n | 3 | 3 | 3 | 3 | 1 | 2 | 1 | 1 |

they are too lean and small due to low salinity. Thus, even this extreme approach gives less than 1% of the yearly background radiation dose. Taking Mytilus from station 12 at Ringhals as a more realistic example gives 0.2 μSv $y^{-1}$ for the reactor-produced nuclides $^{58}Co$, $^{60}Co$, $^{65}Zn$ and $^{110m}Ag$, whereas the 3 natural isotopes reported here ($^{226}Ra$, $^{228}Ra$ and $^{228}Th$) contributes with 15 μSv $y^{-1}$ based on results in Table 3.2.2.2.

## 3.2.3. γ-emitting radionuclides in fish

Table 3.2.3.2 shows results from Ringhals 1982. The dose commitment to a hypothetical critical individual consuming 100 kg fish meat yearly from the vicinity of Ringhals would be approximately 4.5 μSv $y^{-1}$ based on the results shown here. Of this dose the power plants are responsible for only approximately 0.2 μSv, as the radiocesium originates mainly from Sellafield and from fallout.

## 3.2.4. γ-emitting radionuclides in sea sediments

As previously, sediments sampled by the HAPS bottom corer were sliced in 3 cm thick sections and analysed by γ-spectrometry (cf. Tables 3.2.4.1-3.2.4.4). $^{60}Co$ originating from the power plants was detectable at both sites.

Tables 3.2.4.5 and 3.2.4.6 show results from a sample collected further away from Ringhals. A comparison indicates, as expected, that only $^{60}Co$ comes from the power plant.

Table 3.2.2.4. Activity ratios on dry weight basis, Mytilus edulis soft part (from Table 3.2.2.2) to Fucus vesiculosus and Fucus serratus (from Table 3.2.1.2) collected at Ringhals in 1982

| Brown algae | Location | Date | $^{60}Co$ | $^{58}Co$ | $^{65}Zn$ | $^{137}Cs$ | $^{110m}Ag$ | $^{54}Mn$ | $^{95}Zr$ | $^{144}Ce$ | $^{134}Cs$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Fucus vesiculosus | 12 | 7/7 | 0.31 | 0.27 | 1.70 | 0.26 | - | - | - | 0.52 | - |
| Fucus vesiculosus | | | | | | | | | | | |
| Mean 1977-1982 | | | 0.36 | 0.24 | 1.02 | 0.34 | 0.72 | 0.09 | 0.22 | 0.60 | 0.58 |
| S.E. | | | 0.09 | 0.03 | 0.21 | 0.06 | 0.21 | 0.01 | 0.05 | 0.05 | |
| n | | | 11 | 10 | 10 | 8 | 6 | 3 | 3 | 4 | 1 |
| Fucus serratus | | | | | | | | | | | |
| Mean 1977-1982 | | | 0.26 | 0.14 | 0.72 | 0.32 | 0.36 | 0.08 | 0.17 | | |
| S.E. | | | 0.10 | 0.04 | 0.21 | 0.08 | 0.29 | | | | |
| n | | | 7 | 4 | 6 | 4 | 2 | 1 | 1 | 0 | |

Table 3.2.3.1. Gamma-emitting radionuclides in fish meat collected at Barsebäck, location 50, 1982

No samples.

Table 3.2.3.2. Gamma-emitting radionuclides in fish meat collected at Ringhals, location 14, July 9, 1982. (Unit: Bq $kg^{-1}$ fresh weight)

| Species | $^{54}Mn$ | $^{60}Co$ | $^{65}Zn$ | $^{110m}Ag$ | $^{134}Cs$ | $^{137}Cs$ |
|---|---|---|---|---|---|---|
| Dab I | | | 0.50 | | 0.093 | 3.7 |
| Dab II | 0.04 B | | 0.45 | | 0.090 | 1.76 |
| Catfish | | 0.2 A | 0.74 | | 0.15 A | 4.2 |

Table 3.2.4.1. Gamma-emitting radionuclides in sediment samples collected at Barsebäck, location 38, in 1982. (Unit: Bq $kg^{-1}$ dry weight)

| Date | Depth in cm | $^{54}Mn$ | $^{60}Co$ | $^{125}Sb$ | $^{134}Cs$ | $^{137}Cs$ | $^{144}Ce$ | $^{226}Ra$ | $^{228}Ra$ | $^{228}Th$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 21/4 | 0-3 | 1.5 A | 19.7 | 5.9 | 1.71 | 79 | 12.1 | 28 | 24 | 34 |
| " | 3-6 | | 8.4 | | | 54 | | 28 | 28 | 30 |
| " | 6-21 | | | | | 9.4 | | 24 | 32 | 34 |
| 24/6 | 0-3 | | 5.9 | 4.7 | 1.63 | 90 | 4.8 A | 30 | 30 | 34 |
| " | 3-6 | | 1.84 | 3 A | | 50 | | 29 | 32 | 32 |
| " | 6-21 | | | | | 8.2 | | 24 | 35 | 35 |
| 1/12 | 0-3 | 1.43 | 17.2 | 4 A | 1.7 A | 81 | | 27 | 27 | 38 |
| " | 3-6 | | 5.4 | | | 57 | | 29 | 27 | 30 |
| " | 6-12 | | | | | 26 | | 27 | 33 | 35 |

Table 3.2.4.2. Gamma-emitting radionuclides in sediment samples collected at Barsebäck, location 38, in 1982. (Unit: Bq $m^{-2}$) (Area: 0.0145 $m^2$)

| Date | Depth in cm | $^{54}Mn$ | $^{60}Co$ | $^{125}Sb$ | $^{134}Cs$ | $^{137}Cs$ | $^{144}Ce$ | $^{226}Ra$ | $^{228}Ra$ | $^{228}Th$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 21/4 | 0-3 | 16 A | 200 | 60 | 17.5 | 810 | 123 | 280 | 240 | 350 |
| " | 3-6 | | 99 | | | 640 | | 330 | 330 | 360 |
| " | 6-21 | | | | | 620 | | 1590 | 2100 | 2300 |
| 21/4 Σ | 0-21 | 16 | 300 | 60 | 17.5 | 2100 | 123 | 2200 | 2700 | 3000 |
| 24/6 | 0-3 | | 50 | 42 | 14.6 | 810 | 43 A | 260 | 270 | 310 |
| " | 3-6 | | 16.6 | 26 A | | 450 | | 260 | 290 | 290 |
| " | 6-21 | | | | | 530 | | 1540 | 2200 | 2300 |
| 24/6 Σ | 0-21 | | 67 | 68 | 14.6 | 1790 | 43 | 2100 | 2800 | 2900 |
| 1/12 | 0-3 | 14 B | 182 | 42 A | 18 A | 860 | | 290 | 290 | 400 |
| " | 3-6 | | 61 | | | 650 | | 320 | 310 | 340 |
| " | 6-12 | | | | | 640 | | 650 | 820 | 850 |
| 1/12 Σ | 0-12 | 14 | 240 | 42 | 18 | 2200 | | 1260 | 1420 | 1590 |

Table 3.2.4.3. Gamma-emitting radionuclides in sediment samples collected at Ringhals, location 2, in 1982. (Unit: Bq $kg^{-1}$ dry weight)

| Date | Depth in cm | $^{54}Mn$ | $^{60}Co$ | $^{125}Sb$ | $^{134}Cs$ | $^{137}Cs$ | $^{226}Ra$ | $^{228}Ra$ | $^{228}Th$ |
|---|---|---|---|---|---|---|---|---|---|
| 9/7 | 0-3 | 0.6 A | 7.3 | 1.5 A | 0.48 | 20 | 19.5 | 15.0 | 18.0 |
| " | 3-6 | | 2.0 | | | 12.0 | 19.9 | 16.3 | 17.8 |
| " | 6-9 | | | | | 4.5 | 20 | 16.6 | 18.4 |
| 23/10 | 0-3 | | 9.7 | | | 18.0 | 22 | 15.3 | 20 |
| " | 3-6 | | 1.36 | | | 8.6 | 22 | 17.9 | 20 |
| " | 6-9 | | 0.6 A | | | 3.1 | 22 | 18.0 | 21 |

Table 3.2.4.4. Gamma-emitting radionuclides in sediment samples collected at Ringhals, location 2, in 1982. (Unit: Bq $m^{-2}$) (Area: 0.0145 $m^2$)

| Date | | Depth in cm | $^{54}Mn$ | $^{60}Co$ | $^{125}Sb$ | $^{134}Cs$ | $^{137}Cs$ | $^{226}Ra$ | $^{228}Ra$ | $^{228}Th$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 9/7 | | 0-3 | 15 A | 197 | 41 A | 12.9 | 540 | 530 | 400 | 480 |
| " | | 3-6 | | 78 | | | 460 | 770 | 630 | 690 |
| " | | 6-9 | | | | | 167 | 750 | 620 | 680 |
| 9/7 | Σ | 0-9 | 15 | 280 | 41 | 12.9 | 1170 | 2000 | 1650 | 1850 |
| 23/10 | | 0-3 | | 260 | | | 490 | 590 | 410 | 540 |
| " | | 3-6 | | 51 | | | 320 | 820 | 670 | 760 |
| " | | 6-9 | | 22 A | | | 121 | 860 | 700 | 800 |
| 23/10 | Σ | 0-9 | | 300 | | | 930 | 2300 | 1780 | 2100 |

Table 3.2.4.5. Gamma-emitting radionuclides in sediment samples collected at Ringhals, 57°14'N 11°53'E, July 9 1982 (Unit: Bq $kg^{-1}$ dry weight)

| "Name" | Depth in cm | $^{60}Co$ | $^{125}Sb$ | $^{134}Cs$ | $^{137}Cs$ | $^{144}Ce$ | $^{226}Ra$ | $^{228}Ra$ | $^{228}Th$ |
|---|---|---|---|---|---|---|---|---|---|
| HAPS | 0-3 | 2.6 | ?.2 A | 1.95 | 85 | 11.3 | 25 | 33 | 43 |
| " | 3-6 | 1.5 A | 5.5 A | 2.2 | 84 | | 24 | 26 | 34 |
| " | 6-21 | | | | 29 | | 23 | 33 | 35 |

Table 3.2.4.6. Gamma-emitting radionuclides in sediment samples collected at Ringhals, 57°14'N 11°53'E, July 9 1982 (Unit: Bq $m^{-2}$) (Area: 0.0145 $m^2$)

| "Name" | | Depth in cm | $^{60}Co$ | $^{125}Sb$ | $^{134}Cs$ | $^{137}Cs$ | $^{144}Ce$ | $^{226}Ra$ | $^{228}Ra$ | $^{228}Th$ |
|---|---|---|---|---|---|---|---|---|---|---|
| HAPS | | 0-3 | 23 | 28 A | 17.0 | 740 | 99 | 217 | 285 | 378 |
| " | | 3-6 | 16 A | 61 A | 25 | 930 | | 269 | 290 | 376 |
| " | | 6-21 | | | | 1840 | | 1450 | 2100 | 2200 |
| | Σ | 0-21 | 39 | 89 | 42 | 3500 | 99 | 1940 | 2700 | 3000 |

# 4. FALLOUT NUCLIDES IN THE ABIOTIC ENVIRONMENT

by A. Aarkrog, Heinz Hansen and J. Lippert

## 4.1. Air

### 4.1.1. Strontium-90

The mean air activity level for 1982: 7 μBq $^{90}Sr$ $m^{-3}$, i.e. 0.3 times the 1981 level. The maximum activity in 1982 was measured in June at 11 μBq $^{90}Sr$ $m^{-3}$.

Figure 4.1.1 shows the quarterly levels of $^{90}Sr$ in air since 1957.

Table 4.1.1. Strontium-90 in air collected at Risø in 1982. (Unit: μBq $m^{-3}$)

| Month | Daily air filters | Weekly air filters |
|---|---|---|
| | Paper | Glass |
| January | 6.5 | 5.8 B |
| February | 10.4 | 7.1 |
| March | 8.0 | 8.9 |
| April | 8.3 | 9.0 A |
| May | 9.3 | 9.3 |
| June | 10.2 | 11.1 |
| July | 7.6 | 4.5 A |
| August | 6.7 | 5.1 A |
| September | 5.2 | 6.8 |
| October | 4.3 | 3.9 B |
| November | 4.7 | 4.3 B |
| December | 3.5 | 3.8 B |
| 1982 | 7.1 | 6.6 |
| 1982 fCi $m^{-3}$ | 0.19 | 0.18 |

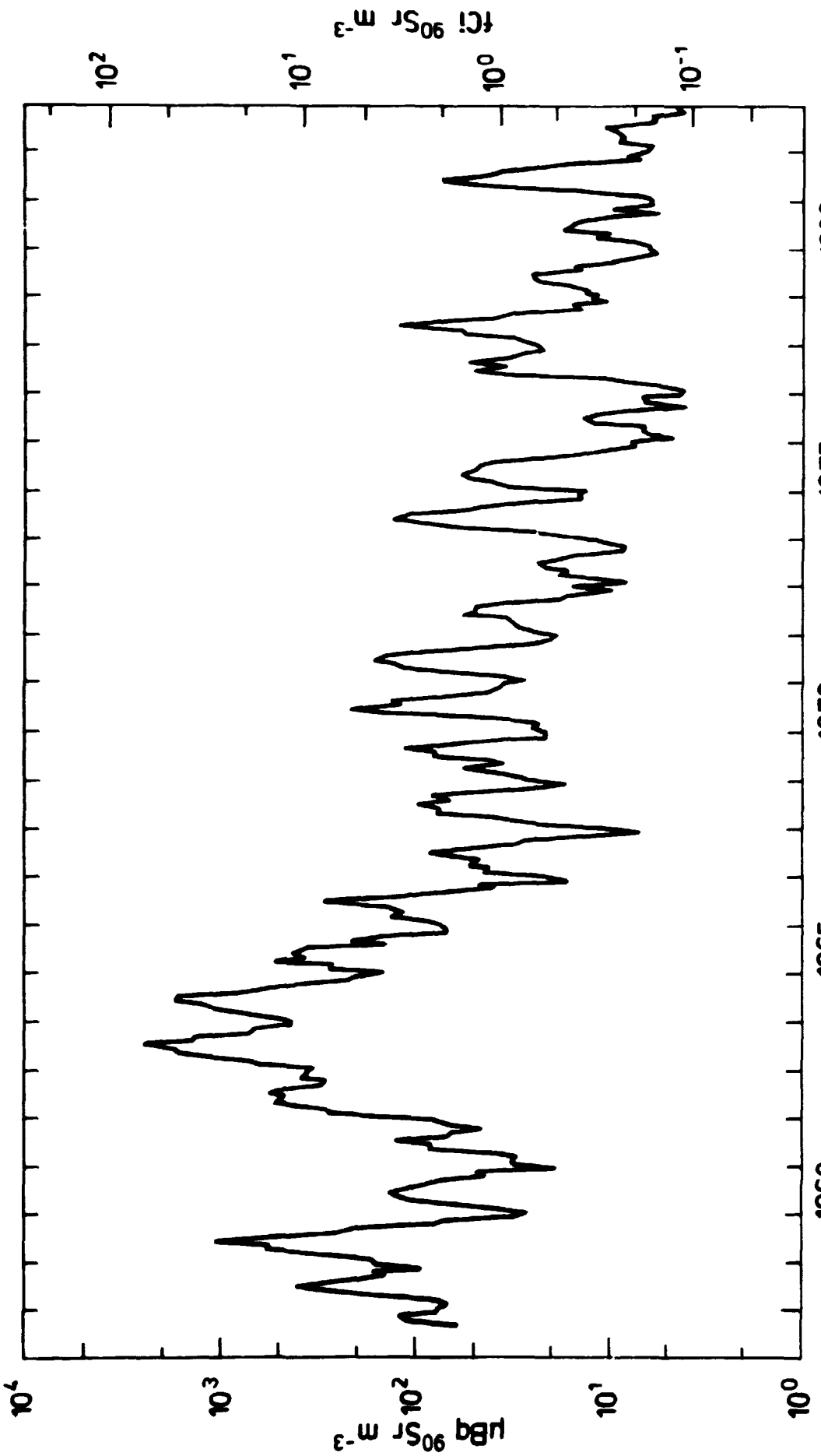


Fig. 4.1.1. Strontium-90 in ground level air at Risø, 1957-1982.

The mean ratio between the monthly $^{90}Sr$ air concentrations measured in the "weekly" and "daily" air samples was 0.95±0.06 (1 SE, N = 12), i.e. not significantly different from one.

## 4.1.2. Cesium-137

Air samples were collected weekly by means of a "new" air sampler installed in 1979 at Risø. The sampler collects the air dust on 6 glassfibre filters each 56 × 48 $cm^2$. The filters collect approximately 275,000 $m^3$ in one week. Similar samplers have been operated during the April-June 1982 in Bornholm and in Mors (NW-Jutland).

Table 4.1.2.1. Cesium-137 in glass-fibre air filters collected once a week at three locations in Denmark in 1982. (Unit: μBq $m^{-3}$)

| Month | Risø | NW-Jutland | Bornholm |
|---|---|---|---|
| January | 4.4 ±1.31 | | |
| February | 8.4 ±2.67 | | |
| March | 6.8 ±1.27 | | |
| April | 8.1 ±1.00 | 9.4±0.86 | 7.1±1.06 |
| May | 8.7 ±0.67 | 8.1±0.71 | 7.4±0.58 |
| June | 9.8 ±1.35 | 9.3±1.69 | 9.1±1.21 |
| July | 5.6 ±0.50 | | |
| August | 4.8 ±1.72 | | |
| September | 2.6 ±0.57 | | |
| October | 2.5 ±0.51 | | |
| November | 1.55±0.20 | | |
| December | 1.48±0.22 | | |
| 1982 | 5.4 | | |
| 1982 fCi $m^{-3}$ | 0.146 | | |

The error term is the S.E. of the mean of the activity found in 4 or 5 filters collected during a month.

Table 4.1.2.1 shows the monthly $^{137}Cs$ concentrations in air from the three stations. It is evident as in 1981[1] that there was no significant local variation between the three. Hence global air activity in Denmark still seems adequately monitored by one sampling station.

Table 4.1.2.2 shows the annual $^{137}Cs$ concentrations in air collected at Risø since 1958.

The mean $^{137}Cs/^{90}Sr$ ratio in Risø air was 0.8 in 1982 which is nearly a factor of two lower than expected. Risø rain showed thus a ratio of 1.75 and rain from all experimental farms gave a ratio of 1.3.

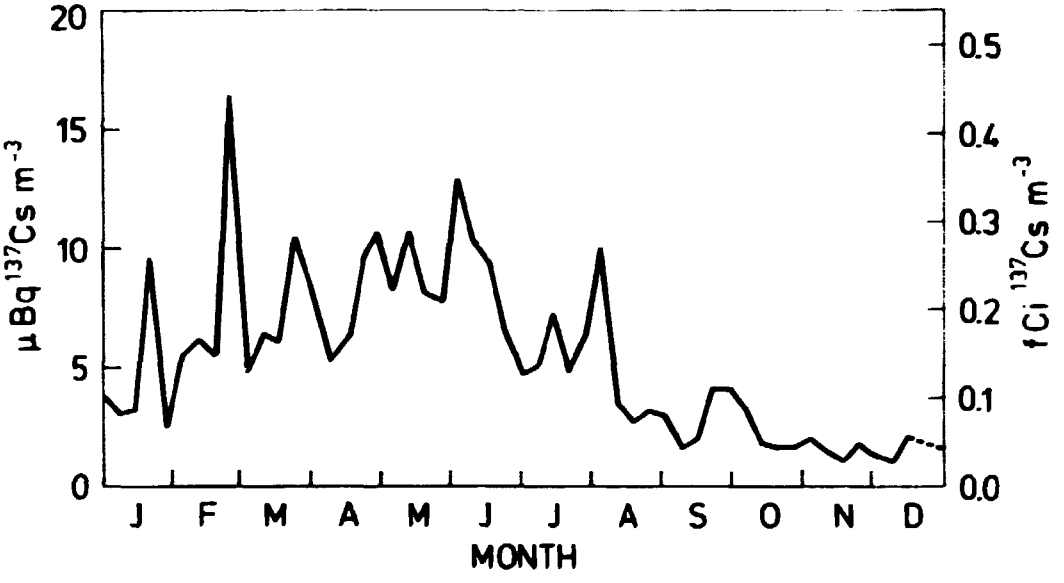


Fig. 4.1.2. Cesium-137 in ground level air at Risø in 1982.

Table 4.1.2.2. Cesium-137 in air collected at Risø 1958-1982

| Year | fCi $m^{-3}$ | μBq $m^{-3}$ |
|---|---|---|
| 1958 | 4.2 | 155 |
| 1959 | 13.1 | 480 |
| 1960 | 1.98 | 73 |
| 1961 | 2.3 | 84 |
| 1962 | 23 | 850 |
| 1963 | 66 | 2400 |
| 1964 | 31 | 1150 |
| 1965 | 10.6 | 390 |
| 1966 | 5.7 | 210 |
| 1967 | 2.1 | 79 |
| 1968 | 2.4 | 88 |
| 1969 | 2.4 | 91 |
| 1970 | 3.4 | 127 |
| 1971 | 2.7 | 98 |
| 1972 | 1.37 | 51 |
| 1973 | 0.47 | 17.3 |
| 1974 | 1.96 | 73 |
| 1975 | 1.30 | 48 |
| 1976 | 0.42 | 15.5 |
| 1977 | 1.62 | 60 |
| 1978 | 1.70 | 63 |
| 1979 | 0.62 | 23 |
| 1980 | 0.24 | 8.7 |
| 1981 | 0.81 | 30 |
| 1982 | 0.146 | 5.4 |

## 4.2. Strontium-90 and various γ-emitters in precipitation

Samples of rain water were collected in 1982 from the State experimental farms (cf. fig. 4.2) in accordance with the principles laid down in Risø Report No. 63, p. 51[1].

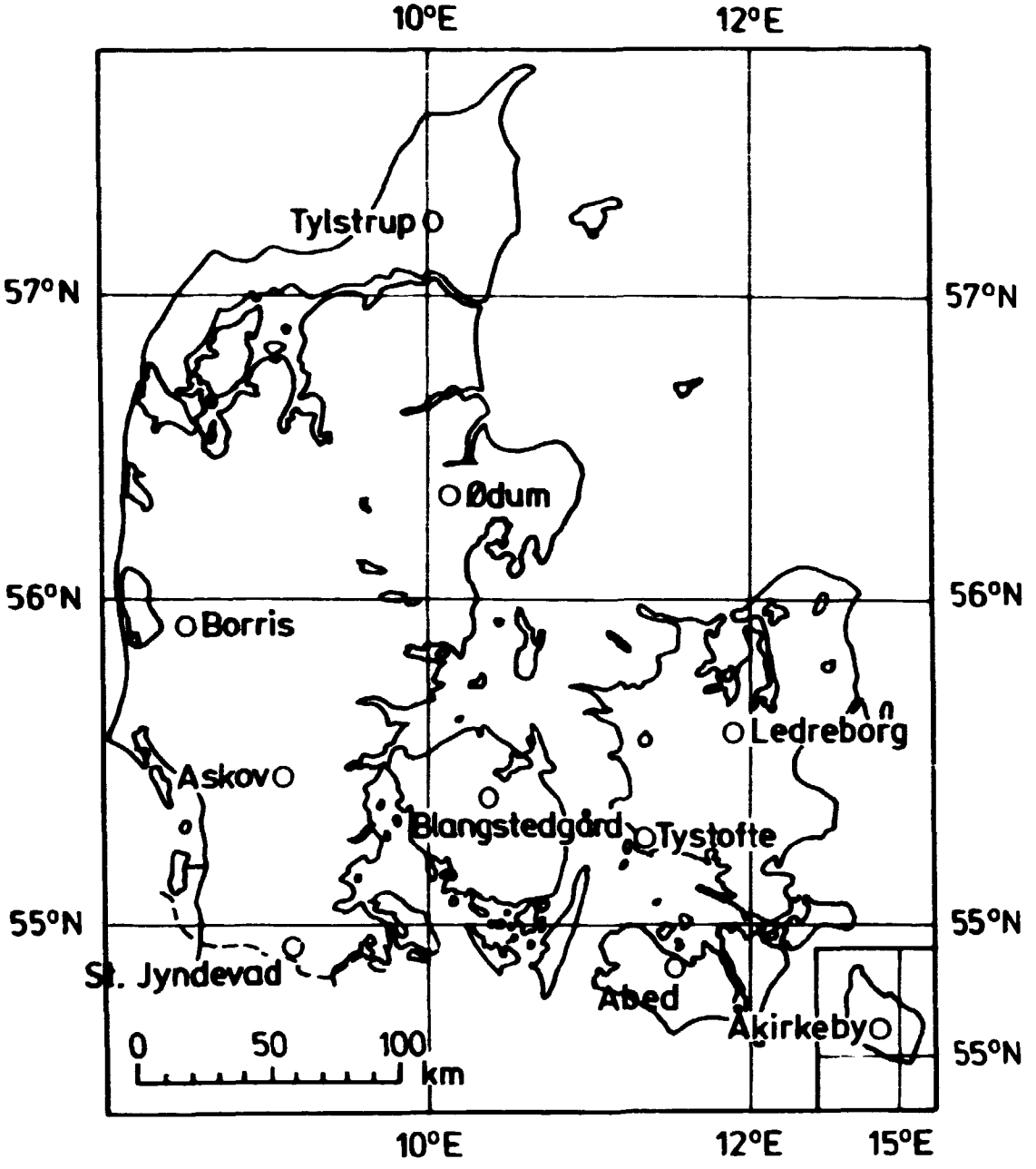


Fig. 4.2. State experimental farms in Denmark.

Table 4.2.1 shows the results of the $^{90}Sr$ determinations and Tables 4.2.2 and 4.2.3 the analysis of variance of the results.

The maximum concentration in precipitation occurred in March-April when the mean content in precipitation was 6 Bq $^{90}Sr\ m^{-3}$, and the maximum fallout rate also occurred in May-June, 0.7 Bq $^{90}Sr\ m^{-2}$. The mean levels for ten State experimental farms were 2 Bq $^{90}Sr\ m^{-2}$ and 3.4 Bq $^{90}Sr\ m^{-3}$. The fallout rate in 1982 was 0.15 times that observed in 1981. The $^{90}Sr$ deposition in 1982 was 0.93 times higher in Jutland than in the Islands.

Table 4.2.1. Strontium-90 fall-out in Denmark in 1982 (sampling area at each location: 0.147 $m^2$)

| Period | Unit | Tylstrup | Borris | Risum | Aakov | St. Jyndevad | Blangstedgård | Tystofte | Abed | Åkirkeby | Ledreborg | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan-Feb | Bq $m^{-3}$ | 4.7 | 4.5 | 9.6 | 5.2 | 5.7 | 4.9 | 8.0 | 6.2 | 9.3 | 9.6 | 6.1 |
| | Bq $m^{-2}$ | 0.22 | 0.36 | 0.25 | 0.33 | 0.31 | 0.164 | 0.28 | 0.194 | 0.28 | 0.151 | 0.25 |
| March-April | Bq $m^{-3}$ | 6.8 | 7.8 | 5.9 | 6.5 | 5.1 | 4.2 | 5.6 | 4.6 | 12.5 | 7.1 | 6.4 |
| | Bq $m^{-2}$ | 0.42 | 0.43 | 0.20 | 0.37 | 0.50 | 0.21 | 0.25 | 0.28 | 0.50 | 0.30 | 0.35 |
| May-June | Bq $m^{-3}$ | (4.5) | (4.3) | 5.7 | 3.8 | 4.6 | 3.5 | 4.8 | 6.7 | 11.9 | 4.1 | 5.0 |
| | Bq $m^{-2}$ | (0.75) | (0.88) | 0.65 | 0.70 | 0.51 | 0.57 | 0.50 | 0.56 | 1.01 | 0.63 | 0.68 |
| July-Aug | Bq $m^{-3}$ | 3.6 | 2.7 | 3.1 | 1.75 | 1.83 | 2.8 | 6.5 | 2.9 | 3.2 | 4.7 | 2.8 |
| | Bq $m^{-2}$ | 0.40 | 0.49 | 0.34 | 0.31 | 0.38 | 0.24 | 0.26 | 0.33 | 0.178 | 0.31 | 0.32 |
| Sept-Oct | Bq $m^{-3}$ | 1.73 | 1.45 | 1.64 | 1.17 | 1.47 | 2.2 | 3.4 | 2.2 | 7.4 | 2.5 | 2.2 |
| | Bq $m^{-2}$ | 0.32 | 0.25 | 0.22 | 0.197 | 0.194 | 0.20 | 0.30 | 0.196 | 0.65 | 0.25 | 0.28 |
| Nov-Dec | Bq $m^{-3}$ | 0.67 A | 1.39 | 0.69 | 1.04 A | 0.92 | 0.94 | 1.86 B | 1.59 A | 2.8 | 1.62 | 1.25 |
| | Bq $m^{-2}$ | 0.105A | 0.34 | 0.097 | 0.190A | 0.150 | 0.130 | 0.18 B | 0.166A | 0.26 | 0.166 | 0.179 |
| 1982 | Bq $m^{-3}$ $\bar{x}$ | 3.2 | 3.3 | 3.1 | 2.5 | 2.7 | 2.7 | 4.4 | 3.5 | 7.3 | 3.7 | 3.4 |
| | Bq $m^{-2}$ $\Sigma$ | 2.2 | 2.8 | 1.76 | 2.1 | 2.0 | 1.51 | 1.85 | 1.73 | 2.9 | 1.81 | 2.06 |
| 1982 | pCi $l^{-1}$ $\bar{x}$ | 0.088 | 0.089 | 0.083 | 0.068 | 0.072 | 0.073 | 0.118 | 0.096 | 0.198 | 0.101 | 0.093 |
| | mCi $km^{-2}$ $\Sigma$ | 0.060 | 0.074 | 0.047 | 0.057 | 0.055 | 0.041 | 0.050 | 0.047 | 0.078 | 0.049 | 0.056 |
| m precipitation $\Sigma$ | | 0.684 | 0.827 | 0.563 | 0.842 | 0.766 | 0.565 | 0.425 | 0.487 | 0.394 | 0.485 | 0.604 |

Figures in brackets were calculated from VARJ[12].

Table 4.2.2. Analysis of variance of ln Bq $^{90}Sr$ $m^{-3}$ precipitation in 1982 (from Table 4.2.1)

| Variation | SSD | f | $s^2$ | $v^2$ | P |
|---|---|---|---|---|---|
| Between months | 21.967 | 5 | 4.393 | 50.614 | > 99.95% |
| Between locations | 4.961 | 9 | 0.551 | 6.351 | > 99.95% |
| Remainder | 3.732 | 43 | 0.087 | | |

Table 4.2.3. Analysis of variance of ln Bq $^{90}Sr$ $m^{-2}$ precipitation in 1982 (from Table 4.2.1)

| Variation | SSD | f | $s^2$ | $v^2$ | P |
|---|---|---|---|---|---|
| Between months | 9.081 | 5 | 1.816 | 23.445 | > 99.95% |
| Between locations | 2.096 | 9 | 0.233 | 3.006 | > 99% |
| Remainder | 3.331 | 43 | 0.077 | | |

A comparison between the yearly amounts of precipitation found in the rain gauges used by the Danish Meteorological Institute[9] and the amounts collected in our rain bottles at the same ten locations in 1982 showed a mean ratio of 1.19±0.15 (1 S.D.) between the two sampling systems.

In order to determine the annual $^{137}Cs$ fallout in Denmark, 10% of all rain samples from the ten state experimental farms were pooled into a single sample for 1982.

The concentration in this sample was 4.4 Bq $^{137}Cs$ $m^{-3}$ and the deposit was 2.7 Bq $^{137}Cs$ $m^{-2}$. Hence the observed $^{137}Cs/^{90}Sr$ in fallout became 2.7/2.1 = 1.29 in 1982.

Table 4.2.4. Strontium-90 in rain water collected in a 10 $m^2$ ion-exchange column collector at Risø in 1982

| Month | m | Bq $m^{-3}$ | Bq $m^{-2}$ |
|---|---|---|---|
| January | 0.036 | 1.65 | 0.059 |
| February | 0.008 | 8.4 | 0.070 |
| March | 0.028 | 3.0 | 0.082 |
| April | 0.008 | 6.5 | 0.055 |
| May | 0.065 | 4.8 | 0.31 |
| June | 0.115 | 2.2 | 0.25 |
| July | 0.015 | 4.9 | 0.073 |
| August | 0.042 | 1.78 | 0.074 |
| September | 0.028 | 2.8 | 0.079 |
| October | 0.074 | 1.10 | 0.081 |
| November | 0.030 | 1.63 | 0.050 |
| December | 0.057 | 0.68 | 0.039 |
| 1982 | $\Sigma$ 0.507 | $\bar{x}$ 2.4 | $\Sigma$ 1.23 |
| 1982 | | pCi $l^{-1}$: 0.066 | mCi $km^{-2}$: 0.033 |

The ratio: $^{137}Cs/^{90}Sr$ measured in monthly rain at Risø was 1.75, i.e. higher than the ratio found at the experimental farms; in air we found the ratio as 0.8.

The washout ratios calculated for Risø was $\frac{2.4}{7} = 0.34$ for $^{90}Sr$ and $\frac{4.2}{5.4} = 0.78$ for $^{137}Cs$, these values were lower than the usually observed washout ratio of 1.0[21].

Tables 4.2.4 and 4.2.5 show the $^{90}Sr$ and $^{137}Cs$ levels in rain water collected at the 10 $m^2$ rain collector at Risø. As compared with the State experimental farms in Zealand (Tystofte and Ledreborg in Table 4.2.1) the $^{90}Sr$ fallout (Bq $m^{-2}$) measured at Risø was only 67% and the concentration (Bq $m^{-3}$) was 59%. The amount of precipitation at Risø was 0.507 m which was 111% of the mean of Tystofte and Ledreborg. Our ion exchange column at Risø may thus have been inefficient for the collection of $^{90}Sr$ from precipitation. This could also explain the exceptionally low washout ratio for $^{90}Sr$.

Table 4.2.5. Cesium-137 in rain water collected in a 10 $m^2$ ion-exchange column collector at Risø in 1982

| Month | m | Bq $m^{-3}$ | Bq $m^{-2}$ |
|---|---|---|---|
| January | 0.036 | 3.0 | 0.110 |
| February | 0.008 | 13.9 | 0.117 |
| March | 0.028 | 6.3 | 0.174 |
| April | 0.008 | 12.0 | 0.102 |
| May | 0.065 | 5.5 | 0.36 |
| June | 0.115 | 3.4 | 0.39 |
| July | 0.015 | 8.8 | 0.131 |
| August | 0.042 | 3.9 | 0.21 |
| September | 0.028 | 4.4 | 0.126 |
| October | 0.074 | 1.79 | 0.132 |
| November | 0.030 | 4.8 | 0.146 |
| December | 0.057 | 3.5 | 0.199 |
| 1982 | $\Sigma$ 0.507 | $\bar{x}$ 4.2 | $\Sigma$ 2.2 |
| 1982 | | pCi $l^{-1}$: 0.114 | mCi $km^{-2}$: 0.059 |

The surface of the 10 $m^2$ rain collector is washed every month with diluted $HNO_3$ and after evaporation the washwater is added to the ion exchange resin before the analysis.

The tritium content of rain-water in 1982 (cf. Table 4.2.6.) was 62% of the 1981 level and the fallout (kBq $m^{-2}$) had decreased by

Table 4.2.6. Tritium in precipitation collected at Risø in 1982

| Month | 1 $m^2$ rain collector | | | 10 $m^2$ rain collector | | |
|---|---|---|---|---|---|---|
| | m | kBq $m^{-3}$ | kBq $m^{-2}$ | m | kBq $m^{-3}$ | kBq $m^{-2}$ |
| Jan | 0.036 | 3.3±0.7 | 0.119 | 0.036 | 10.6±0.6 | 0.38 |
| Feb | 0.008 | 4.1±0.4 | 0.033 | 0.008 | 8.1±0.0 | 0.065 |
| March | 0.032 | 3.7±0.4 | 0.118 | 0.028 | 9.1±0.9 | 0.26 |
| April | 0.015 | 5.9±0.4 | 0.089 | 0.008 | 9.2±1.8 | 0.074 |
| May | 0.063 | 4.8±0.7 | 0.30 | 0.065 | 7.8±0.4 | 0.51 |
| June | 0.115 | 3.9±0.2 | 0.45 | 0.115 | 8.0±0.6 | 0.92 |
| July | 0.014 | 6.3±0.7 | 0.088 | 0.015 | 10.6±0.6 | 0.159 |
| Aug | 0.054 | 5.4±1.3 | 0.29 | 0.012 | 9.6±0.7 | 0.40 |
| Sept | 0.026 | 4.6±0.2 | 0.120 | 0.028 | 6.8±2.0 | 0.190 |
| Oct | 0.074 | 6.3±0.7 | 0.47 | 0.074 | 7.4±0.7 | 0.55 |
| Nov | 0.030 | 3.5±0.2 | 0.105 | 0.030 | 13.0±0.7 | 0.39 |
| Dec | 0.057 | 5.4±0.6 | 0.31 | 0.057 | 10.6±0.9 | 0.60 |
| 1982 | $\Sigma_m$ 0.524 | $\bar{x}$ 4.8 | Σ 2.49 | $\Sigma_m$ 0.506 | $\bar{x}$ 8.9 | Σ 4.5 |

The error term is 1 S.E. of the mean of double determinations.

nearly a factor of two. This is a slower decrease than observed for $^{90}Sr$ and $^{137}Cs$, because tritium in rain depends also upon the accumulated deposition from previous years (cf. 7).

Table 4.2.7 shows the tritium concentrations in rain-water from three other locations in Denmark. Compared with Risø the average concentration for these three stations was 80% of that from Risø. However, the concentrations from Bornholm were nearly as high as that from Risø. This may reflect the high tritium concentrations in the Baltic Sea as compared with those in the

North Sea. The rain water at the western stations Tylstrup and Jyndevad get tritium from evaporation of North Sea water, while the rain from Bornholm (and Risø) get their tritium to a larger extent from evaporation of Baltic Sea water.

Table 4.2.7. Tritium in precipitation collected in Denmark in 1982. (Unit: kBq $m^{-3}$)

| Date | Tylstrup | Jyndevad | Bornholm |
|---|---|---|---|
| Jan-March | 4.8±0.7 | 4.8±0.0 | 5.2±1.5 |
| April-June | 4.1±0.4 | 3.3±0.4 | 4.4±0.0 |
| July-Sept | 4.6±0.6 | 4.1±1.1 | 4.7±0.7 |
| Oct-Dec | 1.8±0.0 | 2.8±0.2 | 3.7±0.0 |
| Precipitation weighted mean | 3.5 | 3.6 | 4.6 |

The error term is 1 S.E. of the mean of double determinations.

## 4.3. Fresh water

### 4.3.1. Strontium-90 and tritium in ground water

As in previous years[1], ground water was collected in March from the nine locations selected by the Geological Survey of Denmark. Figure 4.3.1.1 shows the sample locations and Table 4.3.1 the results of the $^{90}Sr$, tritium and a $^{226}Ra$ analysis.

The median level of $^{90}Sr$ in 1982 was compatible with the values found since 1967 (cf. Fig. 4.3.1.2) but there seems to be a decreasing tendency with time.

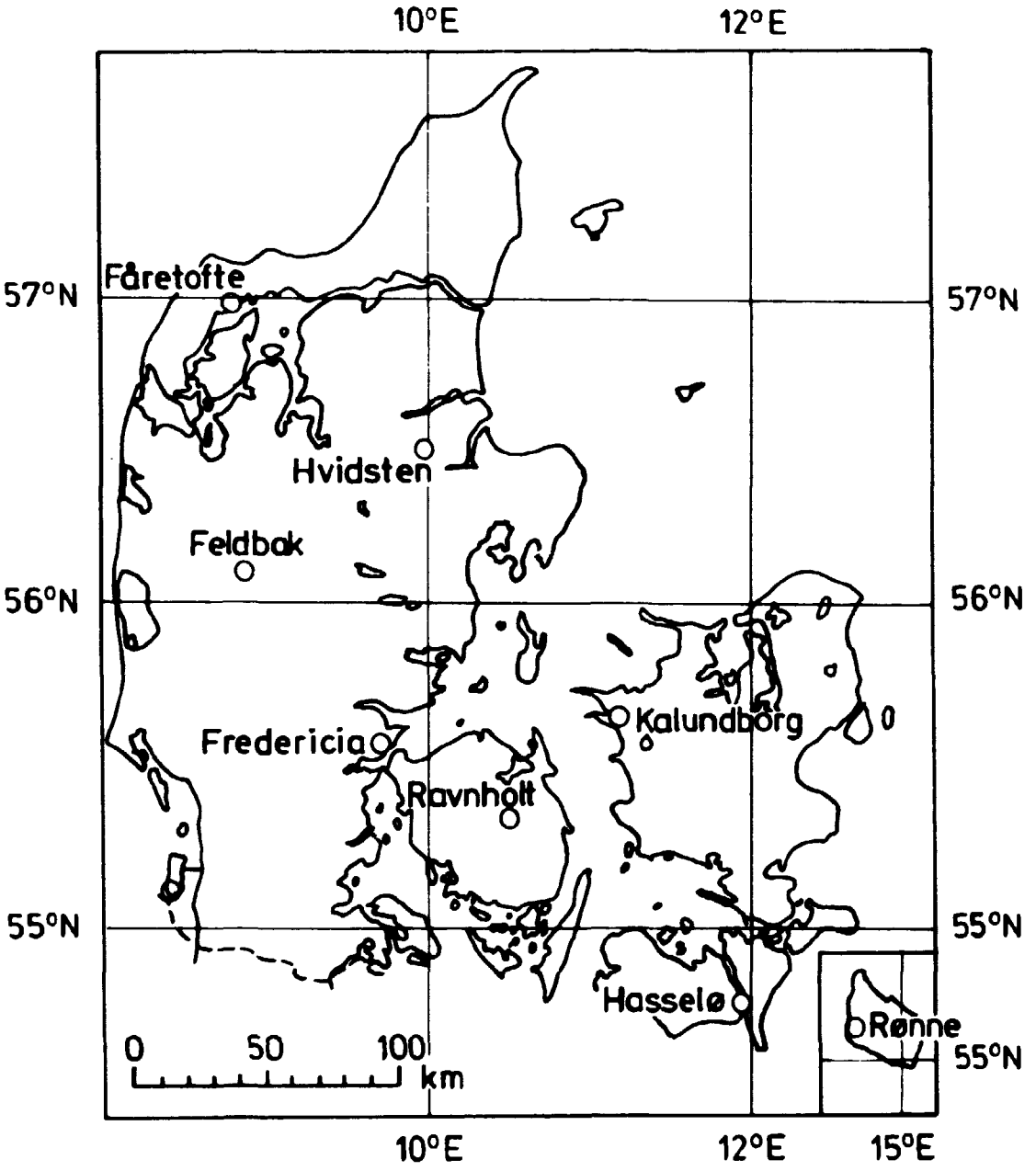


Fig. 4.3.1 1. Ground water sampling locations in Denmark.

Table 4.3.1. Radionuclides in ground water collected in March 1982

| Location | Bq $^{90}Sr$ $m^{-3}$ | kg Ca $m^{-3}$ | kBq $^{3}H$ $m^{-3}$ ±1 S.E. | Bq $^{226}Ra$ $m^{-3}$ |
|---|---|---|---|---|
| Hvidsten | 0.058 | 0.073 | 0.6±0.2 | |
| Feldbak | 121 | 0.037 | 7.3±0.9 | 52±6$^{\Delta}$ |
| Rømø | 0.054 A | 0.030 | 0.9±0.2 | |
| Rønne new | 0.064 A | 0.0096 | 1.1±0.4 | |
| Rønne old | 0.188 | lost | 3.3±0.4 | |
| Hasselø | 0.014 B | 0.138 | 3.2±0.2 | |
| Fåretofte | 0.006 B | 0.148 | 8.7±1.3 | |
| Kalundborg | 1.19 | 0.081 | 5.0±0.2 | |
| Ravnholt | 0.015 B | 0.102 | 5.4±0.6 | |
| Fredericia | 0.60 | 0.085 | 5.2±0 | |
| Geometric mean | 0.145* | 0.078** | 3.8±2.5 (1 SD)** | |
| Median | 0.061 | 0.081 | 3.8 | |
| Geometric mean: pCi $l^{-1}$ | 0.0039 | | 103±68 | |
| Median: pCi $l^{-1}$ | 0.00165 | | 103 | |

A sample of ground water from Maglekilde in Roskilde collected in February 1982 contained 1.05 Bq $^{90}Sr$ $m^{-3}$, 7.0±0.4 kBq $^{3}H$ and 0.168 kg Ca $m^{-3}$.

* Feldbak was not included in the geometric mean.

**Arithmetic mean.

The error term is 1 S.E. of the mean of double determinations.

$^{\Delta}$Triple determinations.

The tritium concentrations in 1982 were 73±5 (1 S.E.)% of the 1981 levels. The tritium content of ground water has been decreasing since 1977 (cf. Fig. 4.3.1.4). The locations may be grouped as "high", "medium" and "low" level stations. Feldbak

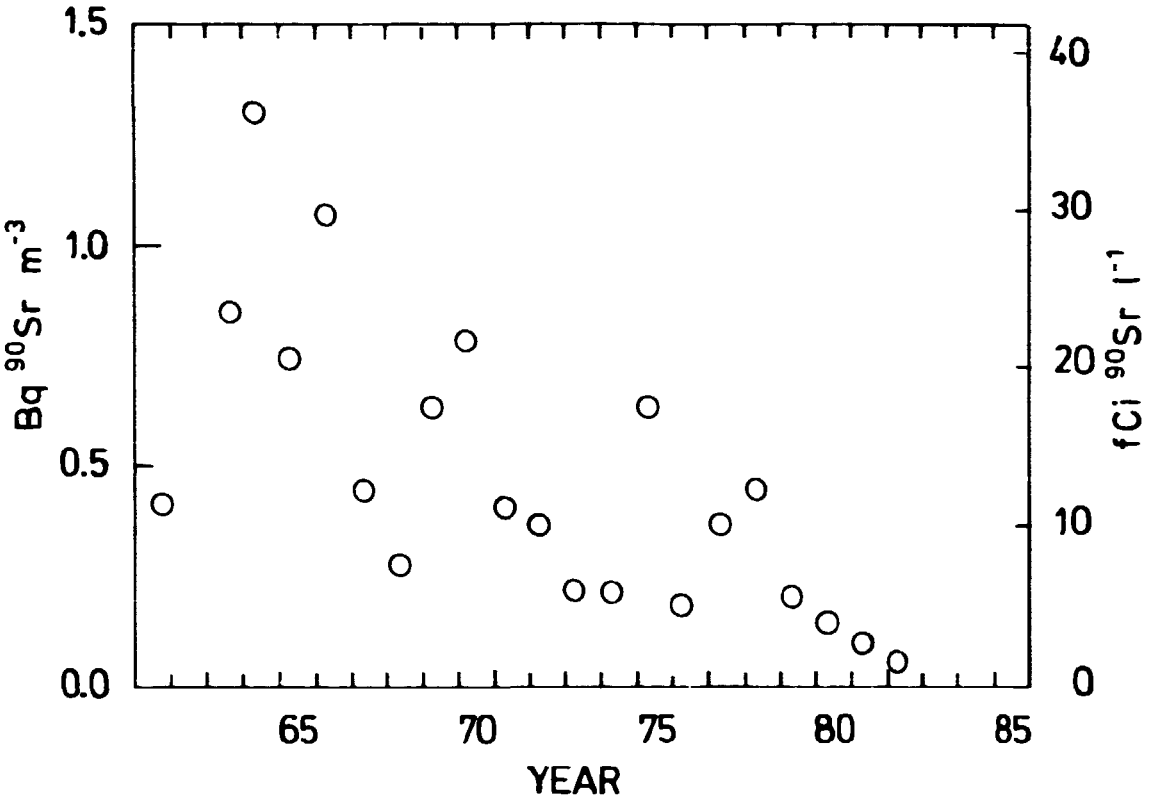


Fig. 4.3.1.2. Median $^{90}$Sr levels in Danish ground water, 1961-1982.

and Fåretofte were not included in this grouping because they showed a time variation different from that of the other stations; in other words, there was an interaction between locations and years if these two stations were included.

Compared with the tritium content of rain-water the 3 "low" stations contained (19±6)% (1 S.D.) of the rain-water levels, the "medium" stations showed (76±10)%, and the "high": (123±29)%. The approximate parallelism between the ground water and rain-water curves suggest that most of the tritium found in ground water is of recent origin. We assume that the water pumped up from the wells consists of fresh precipitation mixed with varying amounts of old (tritium-free) ground water. Only at the two high stations may we see a significant contribution of ground water contaminated with older fallout tritium, from a time when the concentrations were higher than today.

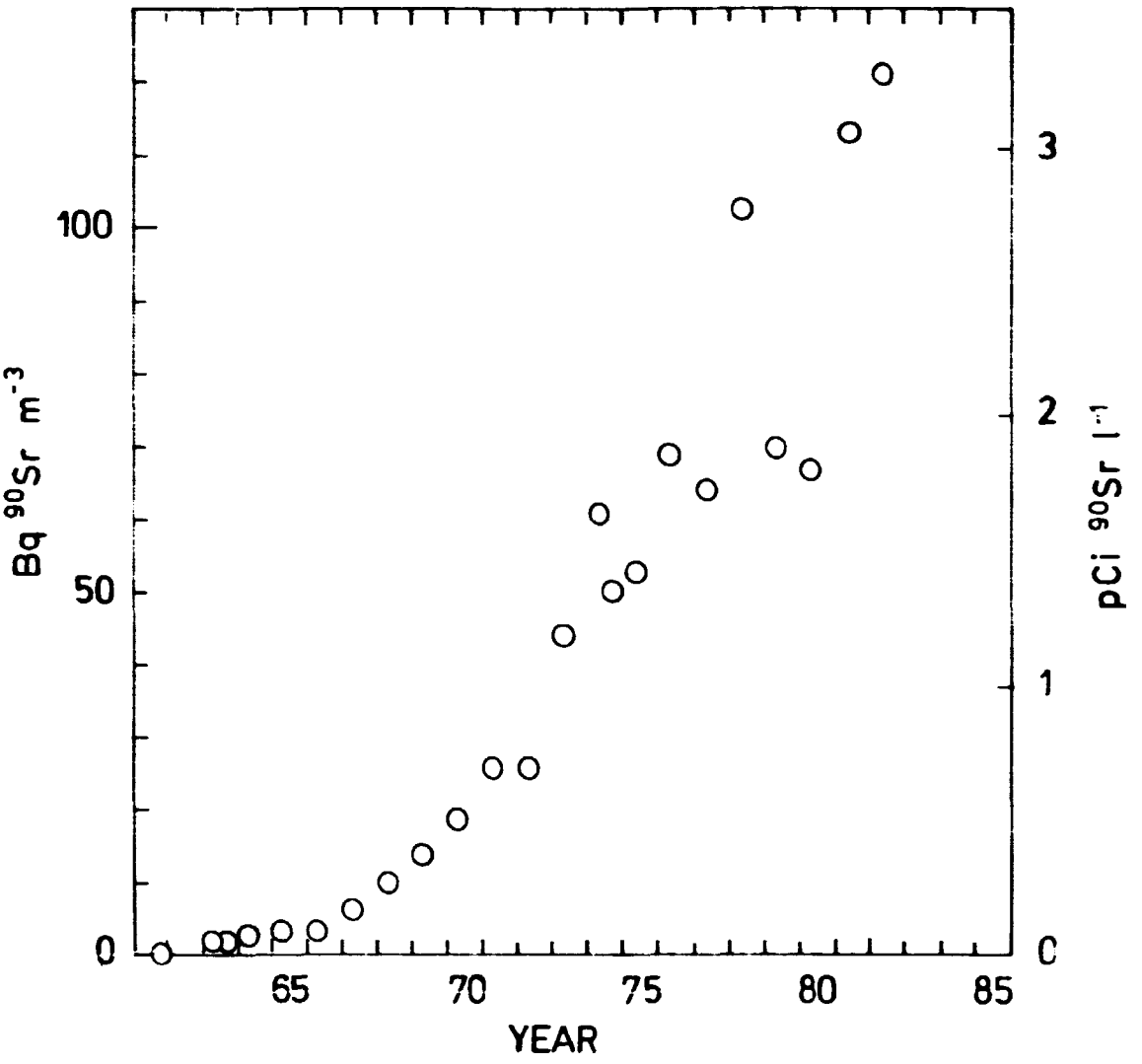


Fig. 4.3.1.3. Strontium-90 in ground water at Feldbak 1961-1982.

The ground water from Feldbak was analysed for $^{226}$Ra, the water contained 52 Bq $^{226}$Ra m$^{-3}$.

As appears from fig. 4.3.1.3, the $^{90}$Sr levels in ground water from Feldbak have been in the order of 50-100 Bq m$^{-3}$ in later years. $^{137}$Cs was not measurable in a 90-l sample of Feldbak water from 1982; the level must have been less than 1.1 Bq $^{137}$Cs m$^{-3}$.

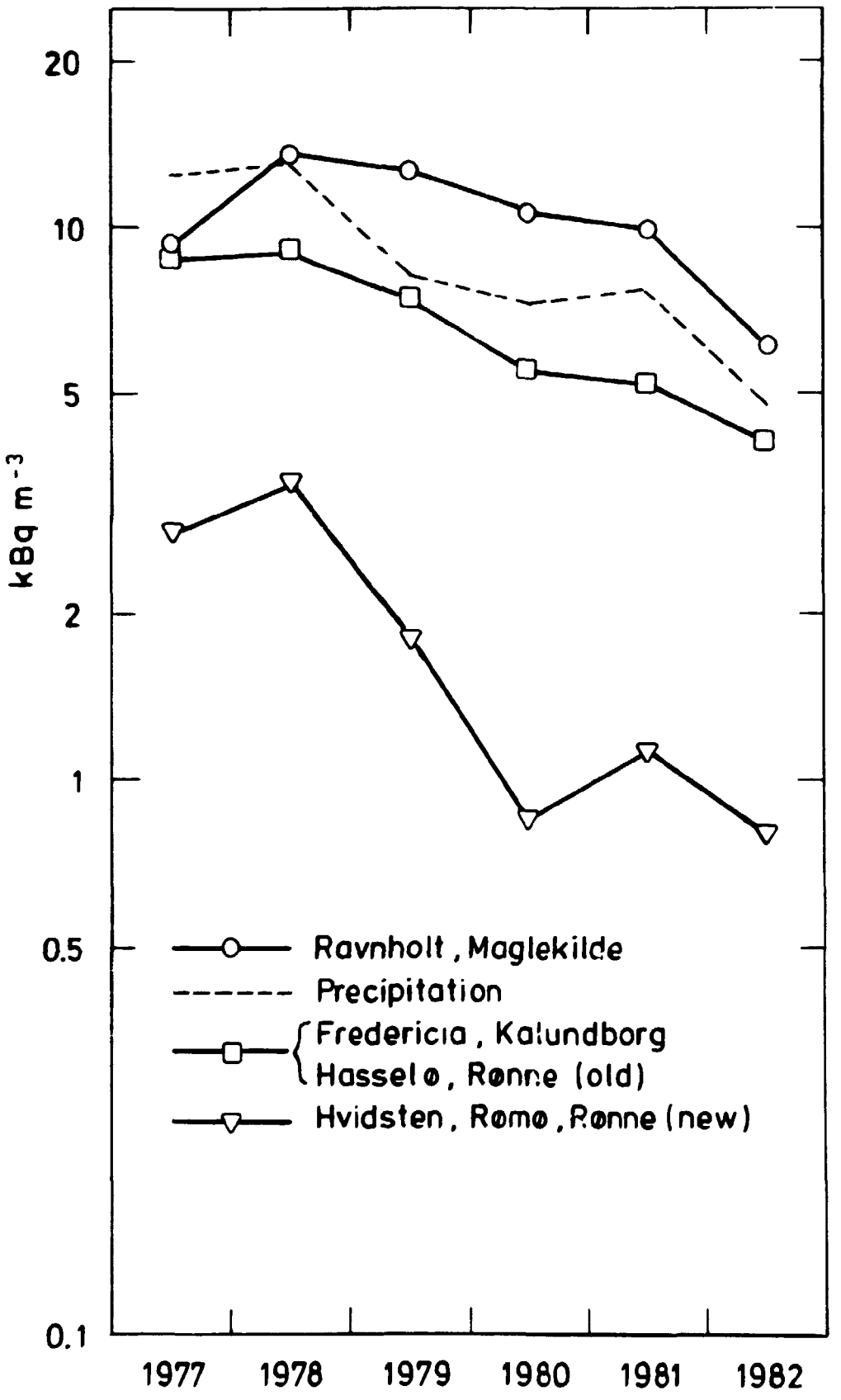


Fig. 4.3.1.4. Tritium in Danish ground water, 1977-1982.

## 4.3.2. Strontium-90 and tritium in fresh water from Danish lakes and streams

No samples in 1982.

## 4.3.3 Strontium-90 and tritium in Danish drinking water

The concentrations were similar to those in 1979 when drinking water was examined last time.

Some zones were lower in 1982 (I, III, V, VI, VIII and Copenhagen) and others were higher (II, IV, VII). The median value in 1982 was half of that in 1979. As compared with ground water the drinking water concentrations were generally higher.

The median level was three times higher in drinking water than in ground water.

Table 4.3.3. Strontium-90 and tritium in drinking water collected in 1982

| Zone | Bq $^{90}Sr$ $m^{-3}$ | kg Ca $m^{-3}$ | kBq $^{3}H$ $m^{-3}$ |
|---|---|---|---|
| I: N. Jutland | 1.60 | 0.057 | 3.7±0.0 |
| II: E. Jutland | 0.47 | 0.089 | 1.8±0.4 |
| III: W. Jutland | 0.25 B | 0.062 | 1.8±0.4 |
| IV: S. Jutland | 0.17 B | 0.143 | 1.8±0.0 |
| V: Funen | 0.089 | 0.133 | 2.8±0.9 |
| VI: Zealand | 0.04 B | 0.094 | 1.3±0.2 |
| VII: Lolland-Falster | 0.054 A | 0.094 | 1.7±0.6 |
| VIII: Bornholm | 1.28 | 0.062 | 2.2 |
| Mean | 0.50 | 0.092 | 2.1 |
| Copenhagen | 0.64 | 0.121 | 4.1±0.7 |
| Median of zones | 0.21 | 0.092 | 1.8 |

The error term is 1 S.E. of the mean of double determinations.

## 4.4. Radionuclides in sea water in 1982

As in previous years, sea water samples were collected by M/S Fyrholm in the summer from inner Danish waters (cf. Table 4.4.1 and figs. 4.4.1 and 4.4.2). Furthermore, sea water samples were collected at Barsebäck in the Sound (Table 4.4.2), and at Ringhals in the Kattegat (Tables 4.4.3 and 4.4.4). Samples were obtained from the research vessel DANA, which in 1982 have collected samples from the Danish straits as well as from the North and the Baltic Seas (Tables 4.4.3 and 4.4.4). Furthermore, samples were obtained from HMS Fylla and from M/S Nella Dan (Table 4.4.3).

Figure 4.4.2 shows that the maximum $^{137}Cs$ concentration in bottom water occurred in 1979, since then the levels have decreased. The surface water seems to begin a decrease in 1982.

As earlier (Risø Reports Nos. 421, 447 and 469)[1] we found in 1982 that the transport time of radiocesium from Sellafield (Windscale) to the Danish straits was approximately 4 years and that about 1% of the $^{137}Cs$ released from Sellafield enters the Baltic Sea. From the regression given in Fig. 4.4.7 the $^{137}Cs$ concentration in 35 o/oo sea water was estimated at 95 Bq $m^{-3}$ and we found 85 Bq $m^{-3}$ according to the equation for $^{137}Cs$ related to salinity in 1982 (Fig. 4.4.8).

As was done earlier we calculated the regression equations between salinity and $^{90}Sr$ and $^{137}Cs$ activity in the sea water:

Bq $^{90}Sr$ $m^{-3}$ = 34.8-0.67 o/oo (1967-1971)
Bq $^{90}Sr$ $m^{-3}$ = 35.9-0.74 o/oo (1972)
Bq $^{90}Sr$ $m^{-3}$ = 35.2-0.52 o/oo (1973)
Bq $^{90}Sr$ $m^{-3}$ = 34.4-0.37 o/oo (1974)
Bq $^{90}Sr$ $m^{-3}$ = 29.2-0.22 o/oo (1975)
Bq $^{90}Sr$ $m^{-3}$ = 26.3-0.074 o/oo (1976)
Bq $^{90}Sr$ $m^{-3}$ = 26.3-0.056 o/oo (1977)
Bq $^{90}Sr$ $m^{-3}$ = 27.8-0.107 o/oo (1978)
Bq $^{90}Sr$ $m^{-3}$ = 27.8-0.31 o/oo (1979)
Bq $^{90}Sr$ $m^{-3}$ = 20.8+0.159 o/oo (1980)
Bq $^{90}Sr$ $m^{-3}$ = 25.9+0.098 o/oo (1981)
Bq $^{90}Sr$ $m^{-3}$ = 26.8-0.197 o/oo (1982)

Table 4.4.1. Strontium-90, Cesium-137 and Cesium-134 in sea water collected around Zealand in June 1982

| | Position N | Position E | Depth in m | $^{90}Sr$ Bq $m^{-3}$ | $^{137}Cs$ Bq $m^{-3}$ | $^{134}Cs$ Bq $m^{-3}$ | Salinity o/oo |
|---|---|---|---|---|---|---|---|
| Kullen | 56°15' | 12°25' | 0 | | 34 | B.D.L. | 14.6 |
| " | | | 22 | | 76 | 2.4 | 33.2 |
| Hesselø | 56°09' | 11°45' | 0 | 24 | 30 | 1.32 | 12.8 |
| " | | | 25 | | 82 | 2.1 | 32.6 |
| Kattegat SW | 56°07' | 11°08' | 0 | | 30 | B.D.L. | 13.7 |
| " | | | 35 | 20 | 74 | 2.4 | 32.0 |
| Asnæs rev | 55°38' | 10°46' | 0 | | 28 | B.D.L. | 12.7 |
| " " | | | 46 | | 73 | 2.8 | 31.5 |
| Halskov rev | 55°23' | 11°03' | 0 | | 23 | B.D.L. | 10.5 |
| " " | | | 26 | 23 | 71 | 1.6 A | 28.8 |
| Langeland bælt | 54°52' | 10°50' | 0 | | 27 | B.D.L. | 13.0 |
| " " | | | 47 | | 69 | 2.1 | 29.2 |
| Femern bælt | 54°36' | 11°05' | 0 | | 28 | B.D.L. | 12.7 |
| " " | | | 26 | | 49 | 1.6 A | 21.5 |
| Gedser odde | 54°28' | 11°59' | 0 | 26 | 17.6 | B.D.L. | 8.2 |
| " " | | | 18 | | 48 | 1.8 A | 19.7 |
| Møen | 54°57' | 12°41' | 0 | 25 | 15.7 | B.D.L. | 7.8 |
| " | | | 22 | | 17.8 | B.D.L. | 8.4 |
| The Sound - South | 55°25' | 12°37' | 0 | | 16.7 | B.D.L. | 8.2 |
| " " " | | | 12 | | 16.8 | B.D.L. | 8.3 |
| The Sound - North A | 55°48' | 12°44' | 0 | | 20 | B.D.L. | 9.2 |
| " " " | | | 20 | | 76 | 1.6 A | 32.9 |
| The Sound - North B | 55°59' | 12°42' | 0 | | 21 | B.D.L. | 10.4 |
| " " " | | | 26 | | 74 | 2.6 | 33.1 |
| Mean | | | Surface | 25 | 24 | | 11.2 |
| S.D. | | | | 1.15 | 6.04 | | 2.39 |
| S.E. | | | | 0.67 | 1.74 | | 0.69 |
| Mean | | | Bottom | 22 | 61 | | 25.9 |
| S.D. | | | | 2.12 | 22.7 | | 9.35 |
| S.E. | | | | 1.50 | 6.55 | | 2.70 |
| Mean: pCi $l^{-1}$ | | | Surface | 0.65 | 0.65 | | |
| S.D. | | | | 0.03 | 0.16 | | |
| S.E. | | | | 0.02 | 0.05 | | |
| Mean: pCi $l^{-1}$ | | | Bottom | 0.59 | 1.65 | | |
| S.D. | | | | 0.06 | 0.61 | | |
| S.E. | | | | 0.04 | 0.05 | | |

Table 4.4.2. Strontium-90, Cesium-137 and Cesium-134 in sea water collected around Zealand in November-December 1982

| | Position N | Position E | Depth in m | $^{90}Sr$ Bq $m^{-3}$ | $^{137}Cs$ Bq $m^{-3}$ | $^{134}Cs$ Bq $m^{-3}$ | Salinity o/oo |
|---|---|---|---|---|---|---|---|
| Kullen | 56°15' | 12°25' | 0 | 25 | 39 | B.D.L. | 16.8 |
| " | | | 24 | 21 | 57 | B.D.L. | 26.2 |
| Hesselø | 56°10' | 11°47' | 0 | | 57 | 2.0 A | 25.5 |
| " | | | 23 | 21 | 65 | 2.7 | 27.9 |
| Kattegat SW | 56°07' | 11°10' | 0 | 22 | 60 | 2.4 A | 25.9 |
| Asnæs rev | 55°38' | 10°47' | 0 | 22 | 60 | 2.5 | 24.1 |
| " " | | | 37 | 20 | 62 | 2.5 A | 26.8 |
| Halskov rev | 55°23' | 11°03' | 0 | 22 | 50 | B.D.L. | 21.9 |
| " " | | | 19 | | 52 | B.D.L. | 23.1 |
| Langeland bælt | 54°52' | 10°50' | 0 | 21 | 50 | 1.3 A | 19.6 |
| " " | | | 17 | 24 | 48 | 1.8 A | 21.0 |
| Femern bælt | 54°36' | 11°05' | 0 | 21 | 43 | B.D.L. | 19.9 |
| " " | | | 17 | 21 | 47 | B.D.L. | 20.7 |
| Gedser odde | 54°28' | 11°59' | 0 | | 43 | 1.5 A | 19.1 |
| " " | | | 15 | 23 | 41 | B.D.L. | 18.0 |
| Møen | 54°57' | 12°41' | 0 | | 16.2 | B.D.L. | 8.2 |
| " | | | 20 | 26 | 34 | B.D.L. | 15.2 |
| The Sound - South | 55°25' | 12°39' | 0 | 27 | 19.6 | B.D.L. | 8.4 |
| " " " | | | 9 | 26 | 36 | B.D.L. | 15.0 |
| The Sound - North A | 55°48' | 12°44' | 0 | 25 | 27 | B.D.L. | 12.6 |
| " " " | | | 21 | 22 | 64 | 2.0 A | 25.3 |
| The Sound - North B | 55°59' | 12°42' | 0 | 24 | 28 | B.D.L. | 13.1 |
| " " " | | | 28 | 19.4 | 63 | 2.8 | 29.5 |
| Mean | | | Surface | 23 | 41 | | 17.9 |
| S.D. | | | | 2.11 | 15.34 | | 6.19 |
| S.E. | | | | 0.70 | 4.43 | | 1.79 |
| Mean | | | Bottom | 22 | 52 | | 22.6 |
| S.D. | | | | 2.35 | 11.40 | | 5.04 |
| S.E. | | | | 0.74 | 3.44 | | 1.52 |
| Mean: pCi $l^{-1}$ | | | Surface | 0.63 | 1.11 | | |
| S.D. | | | | 0.06 | 0.41 | | |
| S.E. | | | | 0.02 | 0.12 | | |
| Mean: pCi $l^{-1}$ | | | Bottom | 0.60 | 1.40 | | |
| S.D. | | | | 0.06 | 0.31 | | |
| S.E. | | | | 0.02 | 0.09 | | |

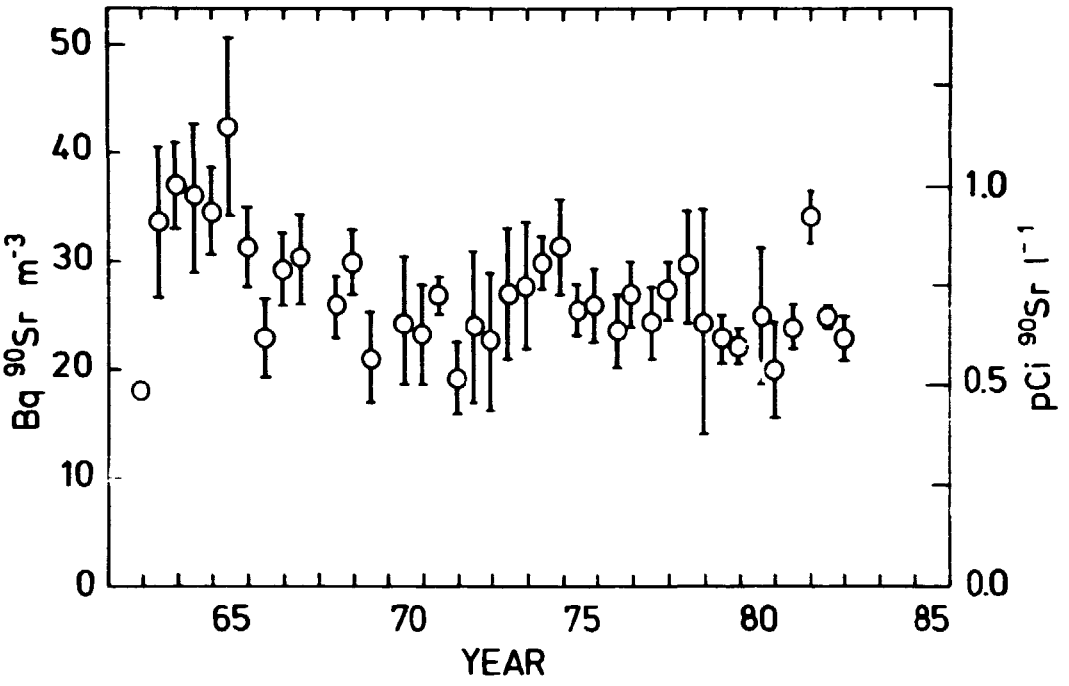


Fig. 4.4.1. Strontium-90 in surface sea water from inner Danish waters, 1962-1982. (1 S.D. indicated) (from Table 4.4.1).

The regression analysis showed only significant regression in 1967-1971, 1972 and in 1974.

Bq $^{137}$Cs m$^{-3}$ = 29.6 -0.16 o/oo (1972)
Bq $^{137}$Cs m$^{-3}$ = 22.2 +0.44 o/oo (1973)
Bq $^{137}$Cs m$^{-3}$ = 20.0 +0.67 o/oo (1974)
Bq $^{137}$Cs m$^{-3}$ = 23.7 +0.37 o/oo (1975)
Bq $^{137}$Cs m$^{-3}$ = 19.6 +0.70 o/oo (1976)
Bq $^{137}$Cs m$^{-3}$ = 15.2 +1.00 o/oo (1977)
Bq $^{137}$Cs m$^{-3}$ = -10.4 +2.85 o/oo (1978)
Bq $^{137}$Cs m$^{-3}$ = -33 3 +4.44 o/oo (1979)
Bq $^{137}$Cs m$^{-3}$ = - 9.1 +3.26 o/oo (1980)
Bq $^{137}$Cs m$^{-3}$ = - 5.0 +3.04 o/oo (1981)
Bq $^{137}$Cs m$^{-3}$ = - 4.11+2.56 o/oo (1982)

The regression analysis showed significant or probably significant regression in all years except in 1972.

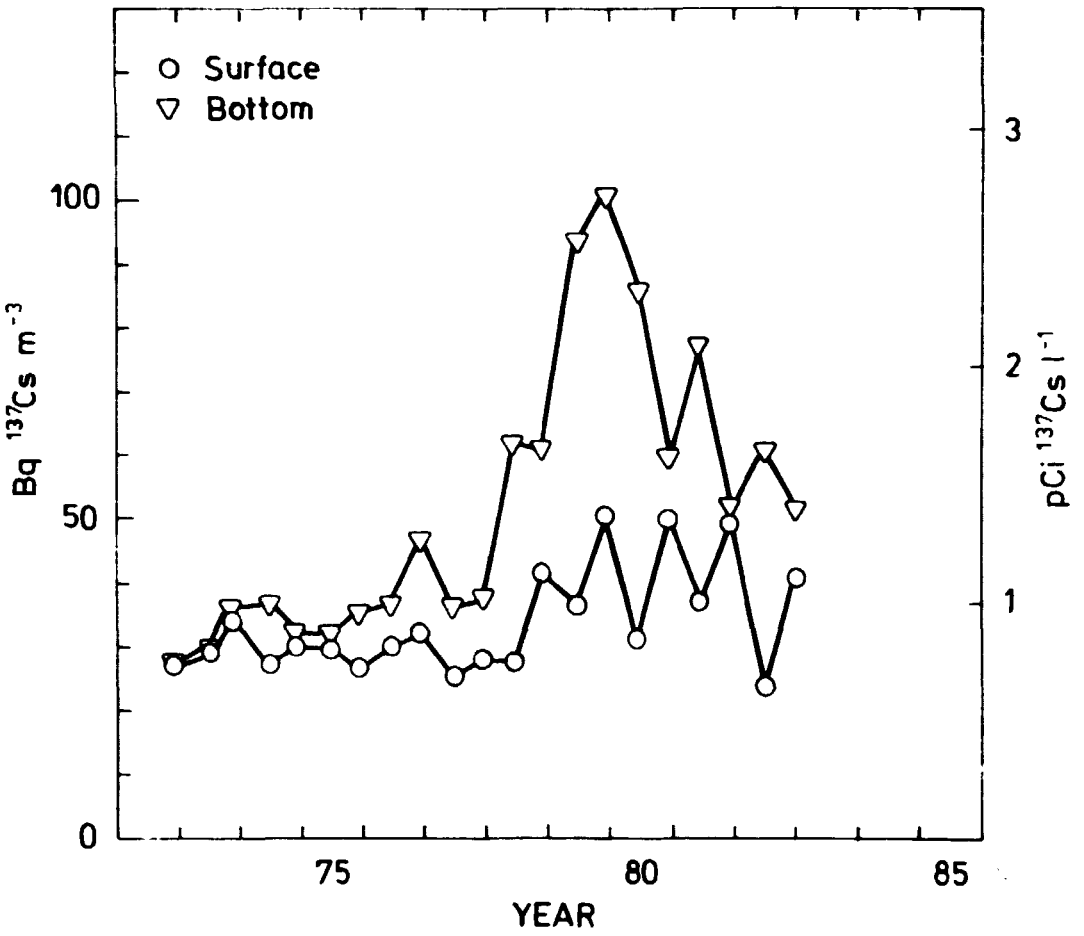


Fig. 4.4.2. Cesium-137 in surface and bottom water collected in inner Danish waters 1972-1982.

A regression analysis of the overall relation between sea water salinity (o/oo) and tritium content (kBq $^{3}H$ $m^{-3}$) shows:

10.4-0.24 o/oo (1979)
12.6-0.26 o/oo (1980)
9.3-0.22 o/oo (1981)
8.6-0.21 o/oo (1982)

This indicates that the tritium contamination of the Danish waters is predominantly due to fallout $^{3}H_3O$ in precipitation. It is unaffected to any significant extent by tritium from Sellafield or from nuclear power plants.

The relations indicate that the tritium concentrations in sea water are decreasing slowly with time. (see also Fig. 7).

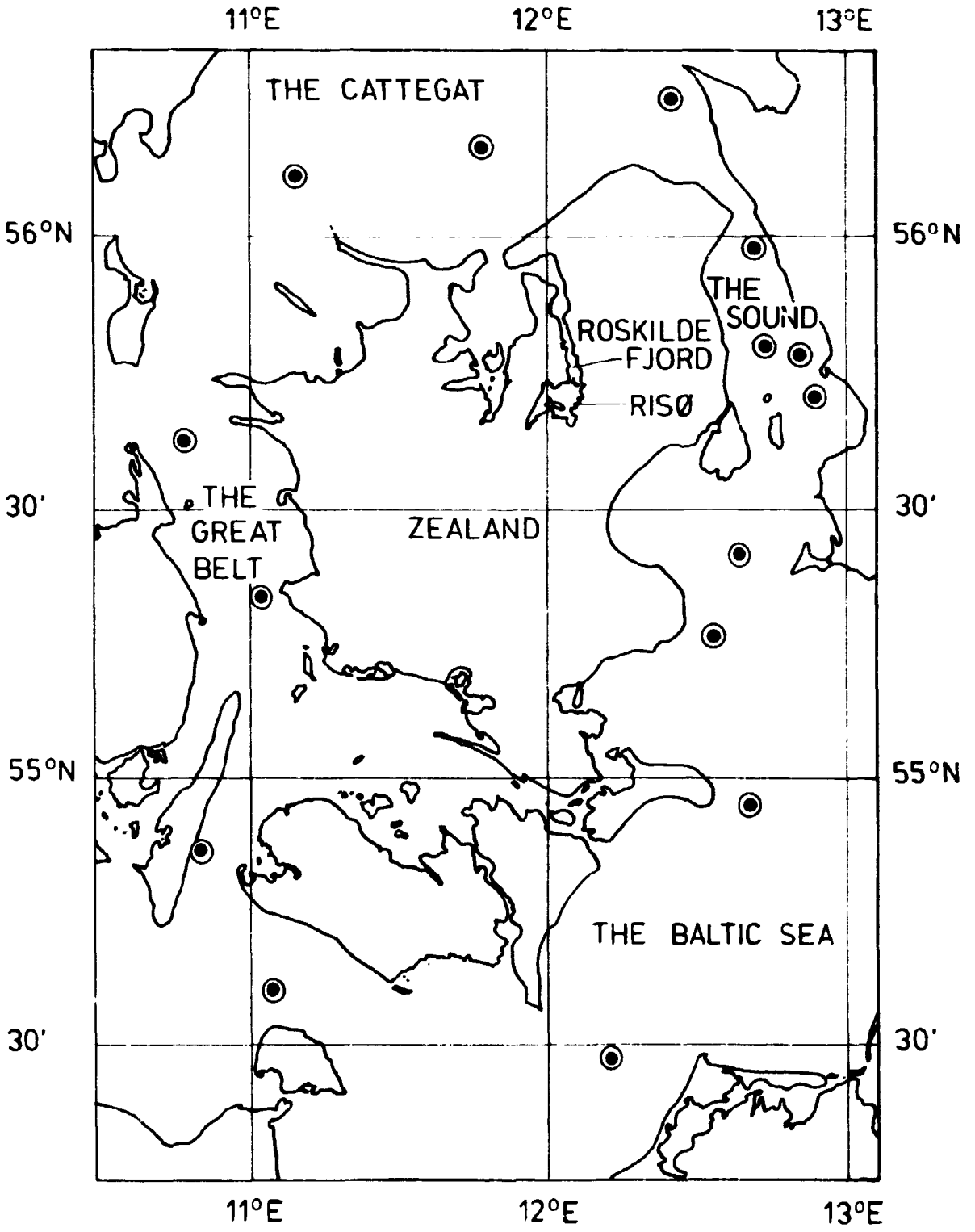


Fig. 4.4.3. Sea water locations around Zealand.

Table 4.4.3. Strontium-90, Cesium-137, Cesium-134 and Tritium in sea water collected in inner Danish waters in 1982

| | Location No. or Position N | E | Date | Depth in m | $^{90}Sr$ Bq $m^{-3}$ | $^{137}Cs$ Bq $m^{-3}$ | $^{134}Cs$ Bq $m^{-3}$ | $^{3}H$ kBq $m^{-3}$ | Salinity o/oo |
|---|---|---|---|---|---|---|---|---|---|
| Barsebäck | Location 38* | | 21/4 | 0 | | 16.4 | B.D.L. | 7.6±0.6 | 8.2 |
| " | " | " | " | 20 | | 70 | 2.4 A | 2.6±0.0 | 32.1 |
| " | " | " | 24/6 | 0 | | 19.2 | B.D.L. | 7.8±0.7 | 8.8 |
| " | " | " | " | 19 | | 73 | 2.2 | 2.2±0.0 | 31.6 |
| " | " | " | 1/12 | 0 | | 26 | B.D.L. | | 12.0 |
| " | " | " | " | 18 | | 60 | 2.0 A | | 27.0 |
| Ringhals | Location 2* | | 9/7 | 0 | | 33 | B.D.L. | 5.6±0.4 | 18.7 |
| " | " | " | " | 20 | 22 | 87 | 3.9 | | 33.2 |
| " | " | " | 23/10 | 0 | | 45 | B.D.L. | | 19.3 |
| " | " | " | " | 25 | | 77 | 2.2 | | 33.8 |
| " | 57°14' | 11°53.07' | 9/7 | 0 | 29 | 43 | 2.0 A | | 18.0 |
| " | " | " | " | 65 | | 87 | 3.6 | 2.0±0.6 | 33.5 |
| Cattegat | 57°39.50' | 11°40.50' | 10/7 | 0 | | 41 | 1.22 | 3.3±0.0 | 17.2 |
| " | " | " | " | 21 | 18.4 | 77 | 3.3 | | 32.8 |
| " | 57°40.00' | 11°25.00' | " | 0 | 25 | 56 | 1.9 A | | 21.3 |
| " | " | " | " | 85 | | 94 | 3.2 | 1.3±0.2 | 34.0 |
| " | 57°41.00' | 11°14.00' | " | 0 | | 64 | 2.3 | 3.0±0.4 | 25.5 |
| " | " | " | " | 35 | 18.6 | 87 | 3.0 | | 32.6 |
| " | 57°41.30' | 11°04.36' | " | 0 | 23 | 59 | 2.5 | | 24.2 |
| " | " | " | " | 30 | | 85 | 3.7 | | 32.5 |
| " | 57°42.00' | 10°55.30' | " | 0 | | 72 | 2.5 | 3.5±0.2 | 25.6 |
| " | " | " | " | 25 | 21 | 81 | 2.7 A | | 31.6 |
| " | 57°42.30' | 10°46.00' | " | 0 | | 64 | 2.1 A | | 23.7 |
| " | " | " | " | 21 | 19.7 | 80 | 3.0 | | 31.8 |
| " | 57°43.00' | 10°37.30' | " | 0 | 18.5 | 61 | 2.2 | | 23.6 |
| " | " | " | " | 13 | | 84 | 2.1 A | 1.7±0.2 | 30.9 |
| The Baltic Sea | 55°19.50' | 15°15.00' | 25/7 | 0 | | 15.2 | B.D.L. | | 7.6 |
| " " " | " | " | " | 89 | | 33 | 0.56 | | 14.6 |
| " " " | 55°05.50' | 14°33.00' | 28/7 | 0 | 23 | 17.[illegible] | B.D.L. | | 7.7 |
| " " " | " | " | " | 36 | 22 | 21 | B.D.L. | | 9.8 |
| " " " | 55°04.00' | 14°09.00' | " | 0 | | 16.2 | B.D.L. | | 7.[illegible] |
| " " " | " | " | " | 42 | | 27 | B.D.L. | 5.6±0.7 | 12.[illegible] |
| " " " | 55°02.60' | 13°46.00' | " | 0 | 25 | 15.4 | B.D.L. | | 7.6 |
| " " " | " | " | " | 45 | 27 | 28 | B.D.L. | | 13.3 |
| " " " | 55°01.50' | 13°23.00' | " | 0 | 26 | 15.6 | B.D.L. | | 7.7 |
| " " " | " | " | " | 42 | | 27 | B.D.L. | 4.7±1.1$^{\Delta}$ | 12.1 |
| " " " | 55°00.00' | 13°00.00' | " | 0 | | 16.8 | B.D.L. | 7.3±1.1$^{\Delta}$ | 7.8 |
| " " " | " | " | " | 21 | 25 | 15.7 | B.D.L. | | 7.9 |
| Roskilde fjord | | | 5/8 | 0 | 19.4 | 24 | B.D.L. | | 10.0 |
| Limfjorden at Thisted | | | 16/3 | 0 | | 36 | 1.90 | 3.7±0.4 | 23.6 |

The error term is ± S.E. of the mean of double determinations.

* Cf. Fig. 3.2.1.

** Cf. Fig. 3.2.2.

$^{\Delta}$ Triple determinations.

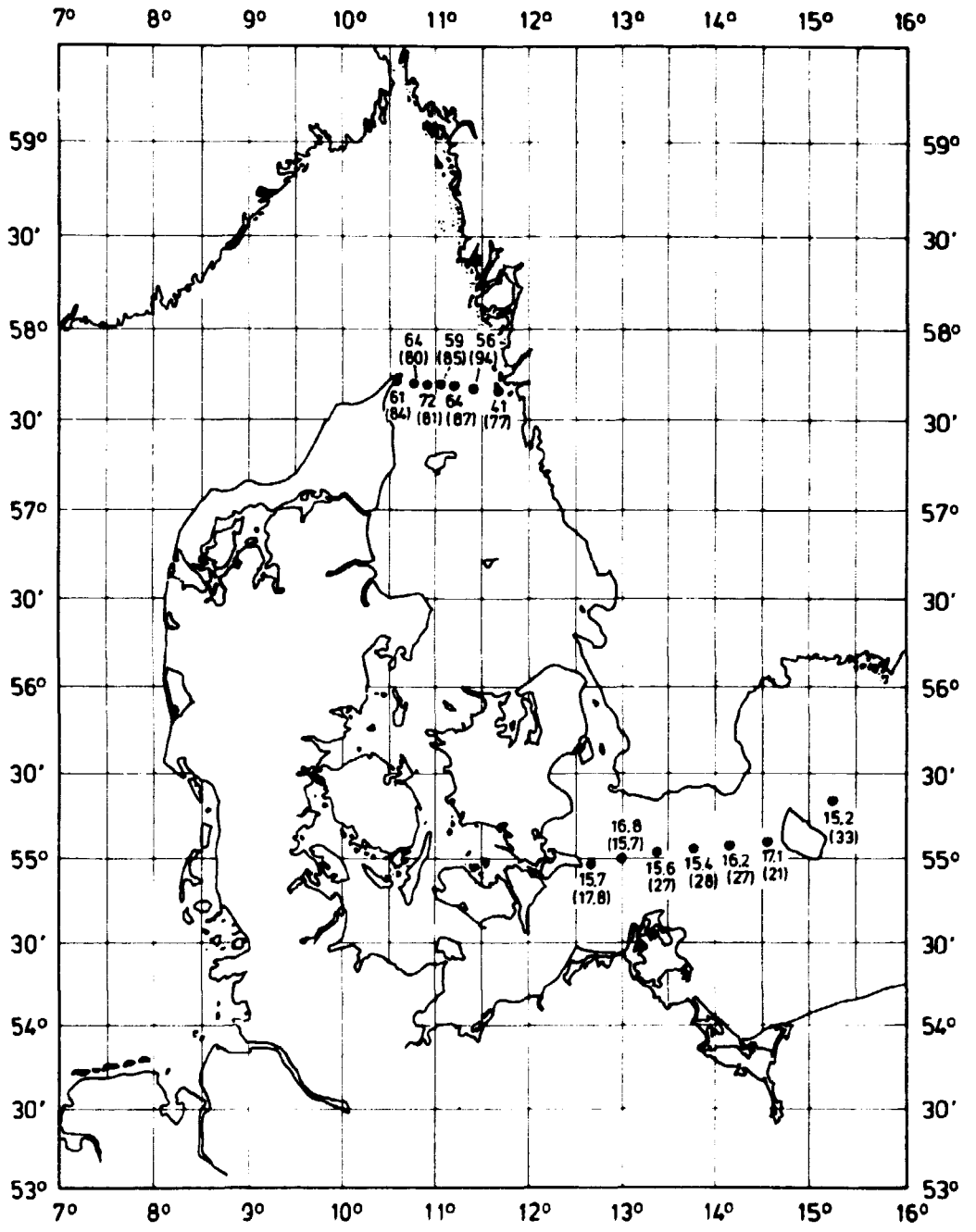


Fig. 4.4.4. Cesium-137 in sea water collected in 1982.
( ) = bottom water. Unit: Bq $m^{-3}$ .

Table 4.4.4. Strontium-90, Cesium-137, Cesium-134 and Tritium in surface sea water collected in the North Sea in 1982

| | Position N | Position E or W | Date | Temp. °C | $^{90}Sr$ Bq $m^{-3}$ | $^{137}Cs$ Bq $m^{-3}$ | $^{134}Cs$ Bq $m^{-3}$ | $^{3}H$ kBq $m^{-3}$ | Salinity o/oo |
|---|---|---|---|---|---|---|---|---|---|
| Nella Dan | 57°49.4'N | 7°44.5'E | 1/8 | | 21 | 63 | 2.0 A | 3.5±0.2 | 26.1 |
| " " | 57°53.1'N | 7°20.8'E | " | | | 69 | 2.2 A | | 27.4 |
| " " | 57°56.4'N | 7°00.2'E | " | | 22 | 66 | 2.0 A | 5.2±0.7 | 26.8 |
| " " | 57°59.9'N | 6°35.8'E | " | 19.0 | | 63 | 2.6 | | 25.4 |
| " " | 58°07.2'N | 6°18.5'E | " | 19.0 | | 64 | 2.4 | | 26.1 |
| " " | 58°15.6'N | 6°01.8'E | " | 17.5 | 18.1 | 66 | 2.1 | 2.2±0.4 | 27.6 |
| " " | 58°24.5'N | 5°45.0'E | " | | | 81 | 3.5 | | 31.4 |
| " " | 58°33.5'N | 5°28.0'E | " | 15.0 | 22 | 92 | 2.7 | 4.6±0.5 | 32.0 |
| " " | 58°41.8'N | 5°11.0'E | " | 15.0 | | 88 | 3.1 | | 32.4 |
| " " | 58°50.9'N | 4°54.1'E | " | 15.0 | | 86 | 3.5 | 2.0±0.2 | 32.4 |
| " " | 58°59.3'N | 4°37.0'E | " | 14.0 | | 78 | 2.9 | | 31.2 |
| " " | 59°07.6'N | 4°17.6'E | " | 14.5 | 17.3 | 72 | 2.8 A | 1.3±0.2 | 31.8 |
| " " | 59°16.1'N | 4°01.2'E | " | 16.0 | | 75 | 2.7 | | 30.1 |
| " " | 59°24.6'N | 3°42.1'E | " | 16.0 | 17.5 | 65 | 2.8 A | 3.2±0.2 | 29.2 |
| " " | 59°33.5'N | 3°25.8'E | " | 16.0 | | 68 | 2.1 | | 30.5 |
| " " | 59°42.3'N | 3°09.3'E | 2/8 | 15.0 | 17.4 | 61 | 2.0 A | 1.8±0.4 | 32.1 |
| " " | 59°50.1'N | 2°50.9'E | " | 15.0 | | 62 | 1.9 A | | 32.3 |
| " " | 59°58.6'N | 2°33.7'E | " | 15.0 | 13.1 | 45 | B.D.L. | 1.5±0.4 | 33.4 |
| " " | 60°07.9'N | 2°16.0'E | " | 15.0 | | 40 | B.D.L. | | 33.6 |
| " " | 60°16.4'N | 2°00.3'E | " | 15.0 | 10.6 | 40 | 1.6 A | 1.8±0.7 | 33.6 |
| " " | 60°25.6'N | 1°43.0'E | " | 15.0 | | 47 | 2.1 | | 32.5 |
| " " | 60°43.6'N | 1°08.2'E | " | 15.0 | 10.1 | 33 | B.D.L. | 0.4 | 34.1 |
| " " | 60°57.4'N | 0°28.6'E | " | 14.0 | | 17.4 | B.D.L. | | 34.7 |
| " " | 61°14.9'N | 0°04.8'E | " | 14.0 | 7.1 | 26 | B.D.L. | 4.1±0.0 | 35.2 |
| " " | 61°31.8'N | 0°39.2'W | " | 13.0 | | 10.8 | 0.4 A | 3.7 | 35.3 |
| " " | 61°33.6'N | 1°59.8'W | 27/8 | 12.0 | 2.1 | 3.5 | B.D.L. | | 34.9 |
| " " | 60°39.4'N | 0°05.0'W | " | 12.0 | | 26 | Spiked | 2.6 | 35.2 |
| Dana | 57°07.15'N | 7°11.23'E | 28/2 | | | 84 | Spiked | | 33.7 |
| " | 57°09.70'N | 6°28.50'E | " | | | 69 | 2.7 | 1.7±0.6 | 34.8 |
| " | 57°33.37'N | 5°17.41'E | 26/2 | | | 47 | 1.96 | 1.5±0.0 | 35.0 |
| " | 58°05.62'N | 3°14.25'E | 1/3 | | | 62 | 2.8 | 1.3±0.2 | 34.9 |
| " | 56°37.73'N | 6°38.01'E | 14/2 | | | 145 | 5.0 | 1.5±0.4 | 34.3 |
| " | 54°46.73'N | 6°40.74'E | 17/2 | | | 31 | 2.0 | 3.2±0.2 | 27.6 |
| " | 54°43.26'N | 3°25.31'E | 18/2 | | 26 | 155 | 5.8 | 1.5±0.0 | 34.4 |
| " | 54°42.90'N | 0°39.50'E | 24/2 | | 23 | 134 | 5.1 | 1.8±0.4 | 34.6 |

Table 4.4.4. (continued)

| | Position N | Position E or W | Date | Temp. °C | $^{90}Sr$ Bq $m^{-3}$ | $^{137}Cs$ Bq $m^{-3}$ | $^{134}Cs$ Bq $m^{-3}$ | $^{3}H$ kBq $m^{-3}$ | Salinity o/oo |
|---|---|---|---|---|---|---|---|---|---|
| Fylla | 59°13'N | 0°35'E | Feb | | 7.8 | 34 | 1.76 | 2.2±0.4 | 35.2 |
| " | 59°36.5'N | 1°18.0'W | " | | 17.5 | 100 | 3.8 | 1.8±0.7 | 35.1 |
| " | 60°14.6'N | 3°28.6'W | " | | 3.1 | 7.2 | B.D.L. | 1.1±0.7 | 35.6 |
| Dana | 57°40'N | 8°14'E | 29/9 | | | 78 | 2.4 | 2.0±0.2 | 28.1 |
| " | 57°40'N | 7°19'E | " | | | 72 | 2.2 A | 1.7±0.2 | 30.8 |
| " | 57°40'N | 6°15'E | " | | | 99 | 3.6 | 1.1±0.0 | 34.5 |
| " | 57°39'N | 5°20'E | " | | | 82 | 3.0 | 1.1±0.0 | 34.5 |
| " | 57°40'N | 4°25'E | " | | | 164 | 6.4 | 1.3±0.2 | 34.9 |
| " | 57°43'N | 3°25'E | " | | | 123 | 5.2 | 0.7±0.0 | 35.0 |
| " | 57°45'N | 2°18'E | " | | | 127 | 5.1 | 1.1±0.0 | 35.0 |
| " | 57°49'N | 0°21'W | " | | | 65 | 4.3 | 1.3±0.2 | 35.2 |
| " | 57°51'N | 1°29'W | 28/9 | | | 200 | 7.9 | 1.1±0.4 | 34.6 |
| " | 57°58'N | 3°44'W | " | | | 220 | 9.2 | 1.1±0.0 | 34.1 |
| " | 57°24'N | 1°44'W | 20/9 | | | 230 | 8.4 | 1.8±0.0 | 34.6 |
| " | 58°44'N | 2°37'W | 18/9 | | | 167 | 7.1 | 2.0±0.2 | 34.6 |
| | 58°25'N | 4°27'W | 18/6 | | | 370 | 16.1 | | |
| | 59°07'N | 3°21'W | 13/6 | 10.0 | | 320 | 13.6 | | 34.5 |
| | 58°44'N | 3°00'W | 12/6 | 9.0 | | 300 | 12.2 | | 34 |
| | 58°30'N | 3°05'W | 17/6 | | | 280 | 11.8 | | |
| | 57°32'N | 2°33'W | 26/6 | | | 310 | 12.7 | | |
| | 56°26'N | 2°32'W | 27/6 | 12 | | 250 | 10.6 | | 34 |
| | " | " | " | 12 | | 290 | Spiked | | 34 |
| | 55°16'N | 1°37'W | 28/6 | | | 137 | 5.4 | | 26 |
| | " | " | " | | | 141 | Spiked | | 26 |
| | 60°48'N | 0°49'W | 14/6 | | | 31 | 1.1 A | | |
| | 59°52'N | 1°18'W | 16/6 | | | 24 | 1.12 | | |

The error term is 1 S.E. of the mean of double determinations.

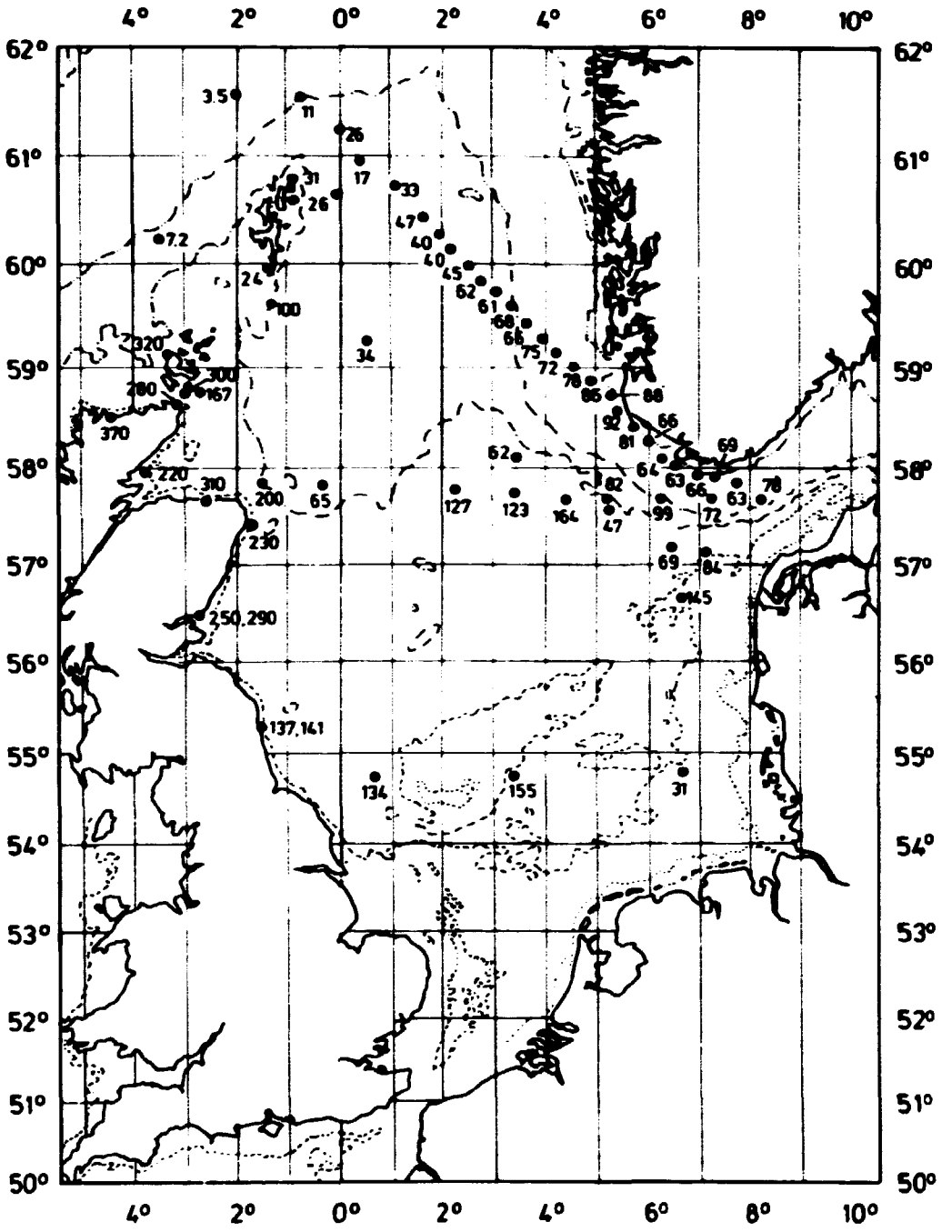


Fig. 4.4.5. Cesium-137 in the North Sea in 1982. (Unit: Bq $m^{-3}$) (cf. Table 4.4.4).

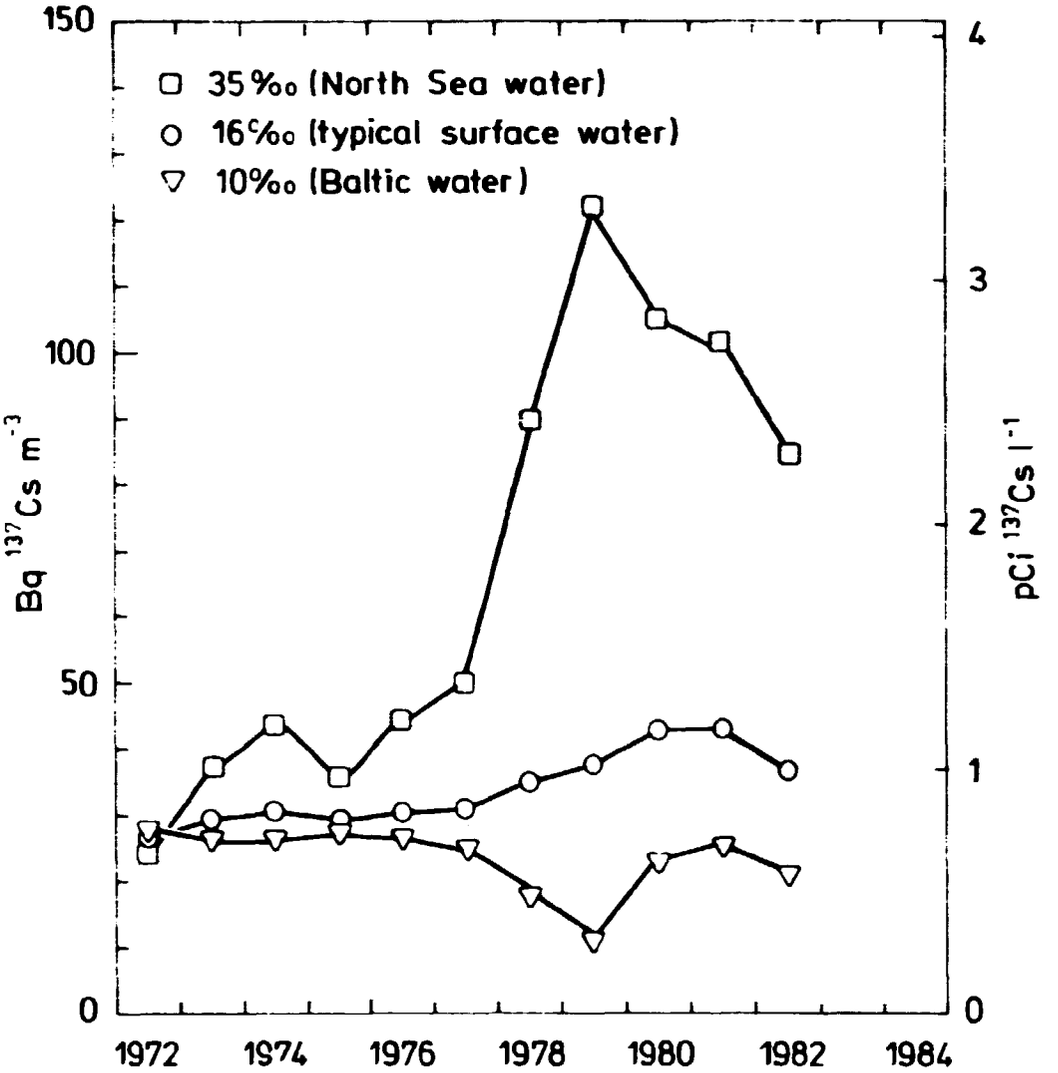


Fig. 4.4.6. Cesium-137 in inner Danish waters of 3 different salinities (1972-1982). The values were calculated from the regression equations in 4.4.

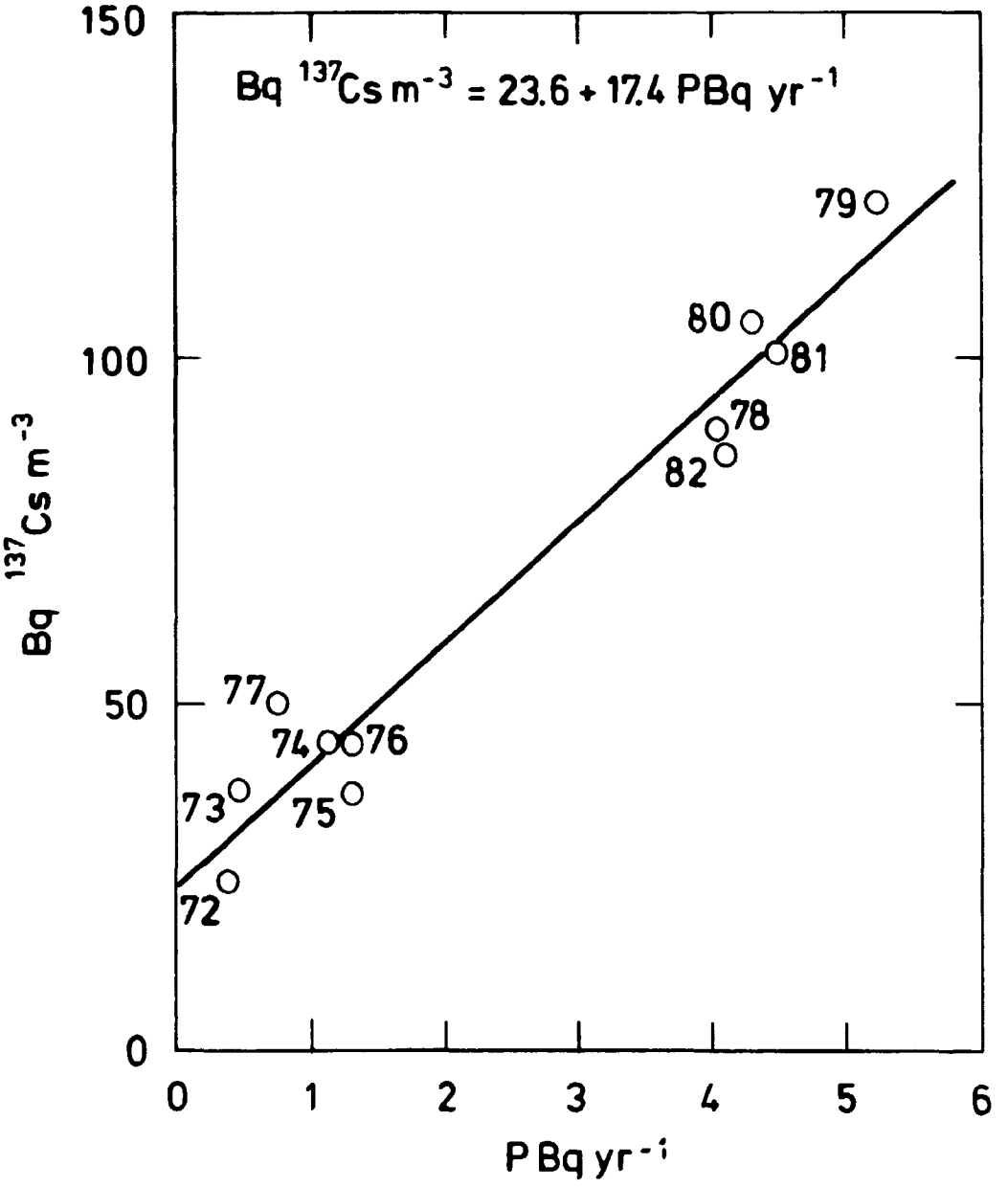


Fig. 4.4.7. Cesium-137 concentrations in "North Sea water" (35 o/oo salinity) in the Danish Straits related to discharges from Sellafield 4 years earlier.

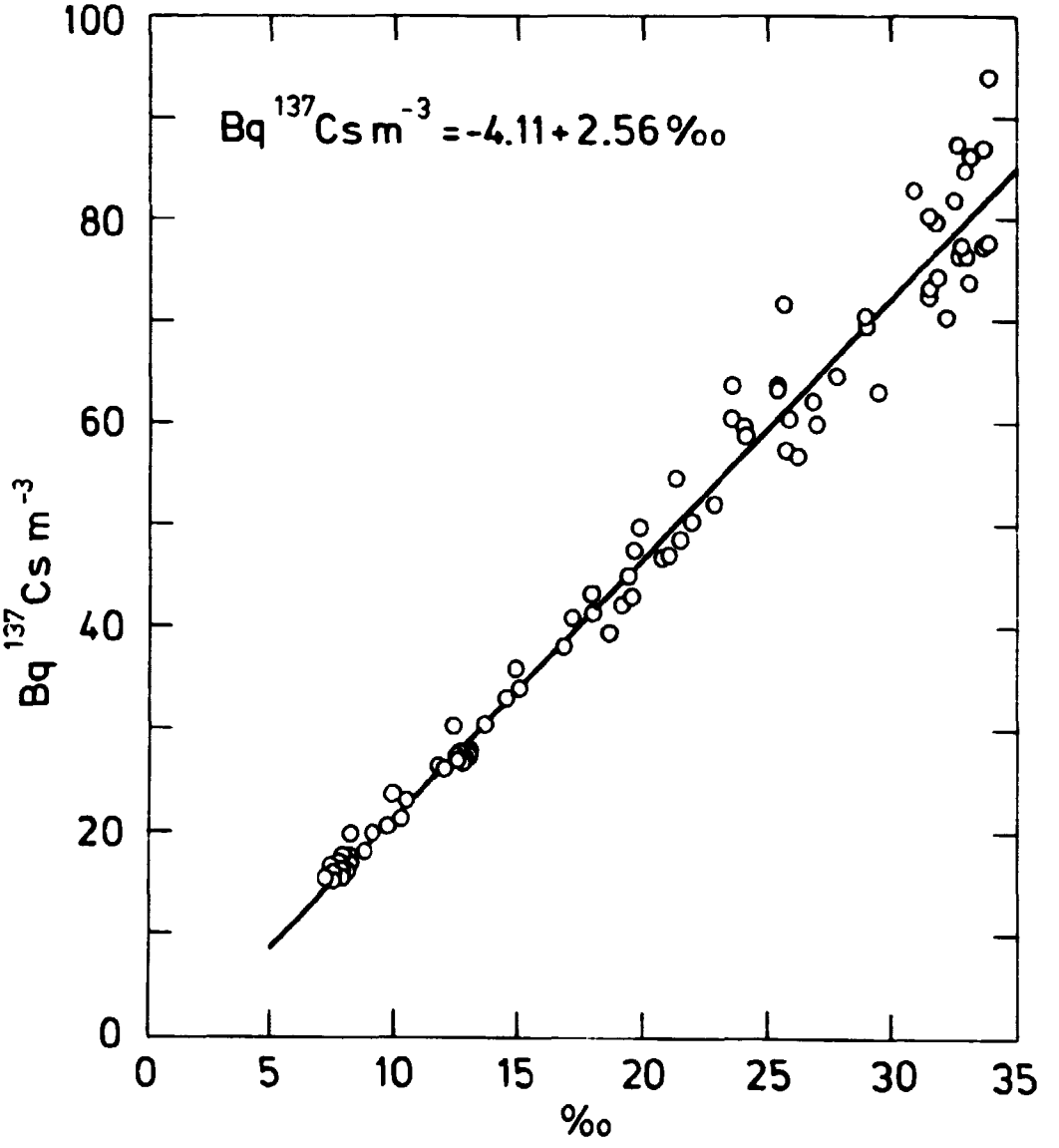


Fig. 4.4.8. Cesium-137 in the Danish Straits related to salinity, 1982.

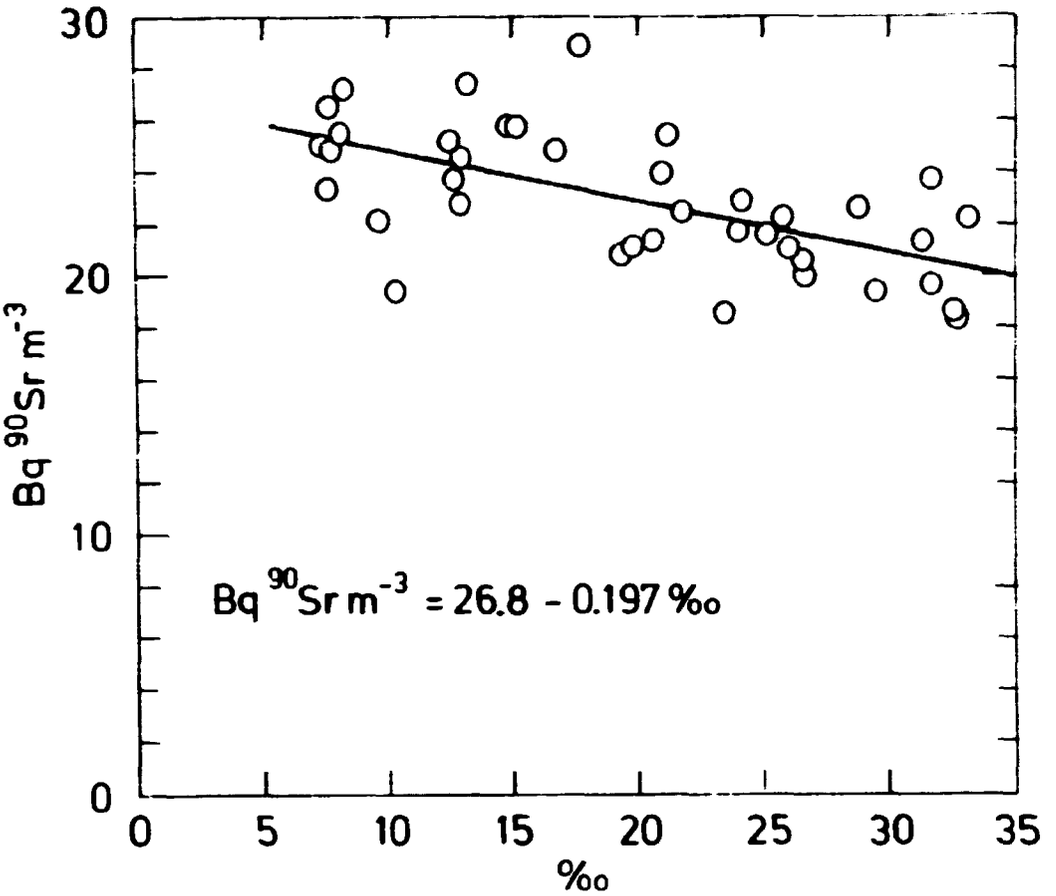


Fig. 4.4.9. Strontium-90 in the Danish Straits related to salinity, 1982.

Table 4.4.5. Strontium-90 in sea water collected in 1981 (Unit: Bq $m^{-3}$)

| Position N | Position E | Depth in m | Date | $^{90}Sr$ |
|---|---|---|---|---|
| 56°09.30'N | 11°51.79'E | | 2/9 -81 | 25 |
| 56°47.12'N | 11°39.31'E | | 1/9 -81 | 28 |
| 56°24.18'N | 11°19.92'E | | 2/9 -81 | 25 |
| 57°20.01'N | 11°18.41'E | | 31/8 -81 | 25 |
| 57°30.17'N | 07°13.39'E | | 16/9 -81 | 26 |
| 57°34.14'N | 10°55.08'E | | 1/9 -81 | 26 |
| 57°38.44'N | 09°27.58'E | | 29/9 -81 | 21 |
| 58°12.20'N | 04°14.60'E | | 26/10-81 | 18.6 |
| 57°57.67'N | 01°10.13'E | | 17/9 -81 | 13.7 |
| 54°45.33'N | 15°17.81'E | | 8/11-81 | 24 |
| 54°52'N | 10°50'E | 50 | 6/12-81 | 29 |
| 55°38'N | 10°47'E | 45 | 2/12-81 | 26 |
| 56°10'N | 11°47'E | 24 | 2/12-81 | 26 |

Table 4.4.6. Tritium in sea water collected in Roskilde Fjord, I (cf. Fig. 4.6.2.), 1982

| Month | kBq $^{3}H$ $m^{-3}$ |
|---|---|
| January | 4.3±0.3* |
| February | 11.7±2.0 |
| March | 9.4±2.4 |
| April | 21 ±0.2 |
| May | 5.7±0.6 |
| June | 9.8±0.2 |
| July | 6.5±0.6 |
| August | 8.9±0.0 |
| September | 7.2±0.2 |
| October | 6.7±1.1 |
| November | - |
| December | 7.8±1.5 |

The error term is 1 S.E. of the mean of double determinations.
*Triple determinations.

Table 4.4.7. Plutonium-239,240 and Americium-241 in sea water collected in inner Danish waters in 1981 and 1982. (Unit: mBq $m^{-3}$)

| Location | Date | Salinity o/oo | $^{239,240}Pu$ | $^{241}Am$ |
|---|---|---|---|---|
| Gudhjem, Bornholm | June 1981 | ~ 7.6 | 3.7 | 1.5 |
| 55°19.50'N 15°15'E | 25 July 1982 | 7.6 | 2.2 | B.D.L. |
| Thisted, Limfjorden | 16/3 | 23.6 | 10.3 | 2.97 |

## 4.5. Strontium-90 in soil

No samples.

## 4.6. Sediments

### 4.6.1. Cesium-137 in sediments collected in Roskilde Fjord

The integrated $^{137}Cs$ mean level (1240 Bq $^{137}Cs$ $m^{-2}$) in sediments from loc. I (cf. Fig. 4.6.1) in the Roskilde Fjord corresponded to the observation in 1979 and 1981[1)].

Table 4.6.1. Cesium-137 in sediment samples collected in Roskilde fjord, I, 1982. (HAPS) (Area 0.0145 $m^2$)

| Depth in cm | Date | Bq $kg^{-1}$ dry | Bq $m^{-2}$ |
|---|---|---|---|
| 0-3 | 27/5 | 14.9 | 310 |
| 3-6 | " | 18.8 | 730 |
| 6-12 | " | 6.3 | 360 |
| 0-12 | | | Σ 1400 |
| 0-3 | 5/8 | 11.7 | 260 |
| 3-6 | " | 14.5 | 400 |
| 6-12 | " | 7.0 | 420 |
| 0-12 | | | Σ 1080 |

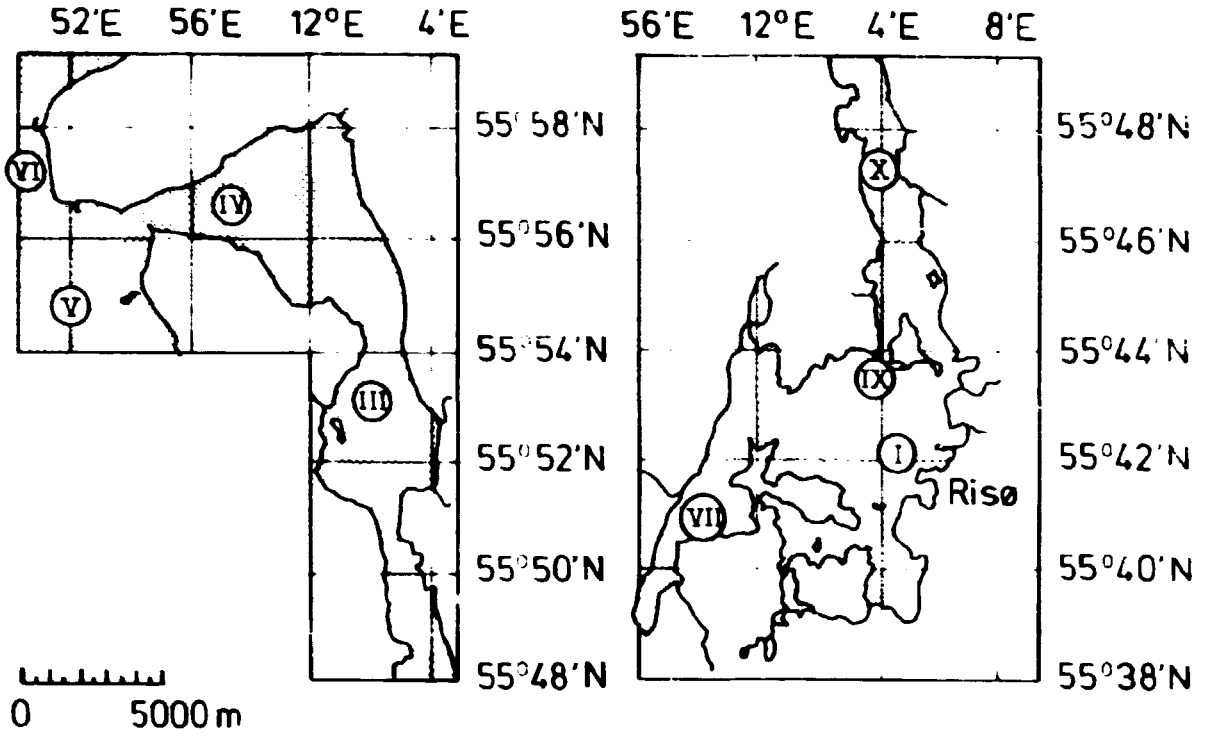


Fig. 4.6.1. Roskilde fjord.

## 4.6.2. Strontium-90 and Cesium-137 in sediments collected in inner Danish waters

The two sediment samplers: HAPS and BENTHOS gave comparable results (Table 4.6.2). Strontium-90 was determined in sediments collected in 1981 in Roskilde Fjord, The Great Belt, The Sound (Barsebäck), and Kattegat (Ringhals) (Table 4.6.3). Compared with the $^{137}Cs$ measurements (Risø-R-469[1]) it appears that the $^{90}Sr$ levels in sediments are approximately 1% of the $^{137}Cs$ concentrations, which demonstrates the greater tendency for $^{137}Cs$ to be attached to minerals.

Table 4.6.2. Cesium-137 in sediments collected in inner Danish waters in 1982

| Location | | Date | Depth in cm | "Name" | Bq $^{137}Cs$ $kg^{-1}$ dry | Bq $^{137}Cs$ $m^{-2}$ |
|---|---|---|---|---|---|---|
| 55°52'N | 12°45'E | 26/5 | 0-5 | Benthos* | 23 | 550 |
| " | " | " | 5-35 | " | 5.2 | 1690 |
| | | | 0-35 | | | Σ 2200 |
| 55°20'N | 15°15'E | 25/7 | 0-3 | HAPS** | 61 | 350 |
| " | " | " | 3-6 | " | 50 | 290 |
| " | " | " | 6-21 | " | 6.8 | 260 |
| | | | 0-21 | | | Σ 900 |
| 55°03'N | 13°46'E | 28/7 | 0-10 | Benthos | 25 | 370 |
| " | " | " | 10-20 | " | 3 A | 80 A |
| " | " | " | 20-30 | " | 2.8 | 80 |
| " | " | " | 30-40 | " | B.D.L. | B.D.L. |
| " | " | " | 40-50 | " | 1 B | 30 B |
| | | | 0-50 | | | Σ 560 |
| 55°03'N | 13°46'E | 28/7 | 0-3 | HAPS | 44 | 320 |
| " | " | " | 3-6 | " | 12.4 | 87 |
| " | " | " | 6-21 | " | 1.1 | 46 |
| | | | 0-21 | | | Σ 360 |

* Benthos area = 0.00353 $m^2$

**HAPS area = 0.0145 $m^2$

Table 4.6.3. Strontium-90 in sediments collected in 1981. (HAPS)
(Area: 0.0145 $m^2$)

| Location | Date | Depth in cm | Bq $^{90}Sr$ $kg^{-1}$ dry | Bq $^{90}Sr$ $m^{-2}$ |
|---|---|---|---|---|
| Roskilde fjord | June | 0-3 | 0.137 | 3.2 |
| " " | " | 3-6 | 0.113 | 2.7 |
| " " | " | 6-9 | 0.059 | 1.80 |
| " " | " | 9-12 | 0.168 | 5.2 |
| | | 0-12 | | Σ 12.9 |
| $55^{o}23'N$ $11^{o}03'E$ | June | 0-3 | 0.26 | 4.0 |
| " " | " | 3-6 | 0.28 | 5.4 |
| " " | " | 6-9 | 0.25 | 4.6 |
| " " | " | 9-12 | 0.094 | 1.63 |
| " " | " | 12-15 | 0.053 | 0.95 |
| | | 0-15 | | Σ 16.6 |
| Barsebäck st. 38* | Sept | 0-3 | 0.92 | 8.8 |
| " " | " | 3-6 | 0.47 | 5.5 |
| " " | " | 6-9 | 0.50 | 6.6 |
| " " | " | 9-12 | 0.32 | 4.1 |
| " " | " | 12-15 | 0.128 | 1.68 |
| | | 0-15 | | Σ 27 |
| Ringhals st. 2** | July | 0-3 | 0.24 | 5.6 |
| " " | " | 3-6 | 0.36 | 11.9 |
| " " | " | 6-9 | 0.131 | 4.8 |
| " " | " | 9-12 | 0.158 | 7.1 |
| | | 0-12 | | Σ 29 |

* Cf. Fig. 3.2.1.1.
**Cf. Fig. 3.2.1.2.

# 5. DANISH FOOD AND VARIOUS VEGETATION

by A. Aarkrog

## 5.1. Strontium-90 and Cesium-137 in dried milk from the entire country

As in previous years, monthly samples of dried milk were collected from seven locations in Denmark (cf. fig. 5.1.1). Table 5.1.1 shows the results of the $^{90}Sr$ determinations and Table 5.1.2 the analysis of variance of the results. As in recent years, the local variation was significant for Bq $^{90}Sr$ (kg Ca)$^{-1}$. Milk from eastern Denmark showed as usual lower levels than the milk from Jutland. The Bq $^{90}Sr$ (kg Ca)$^{-1}$ mean level in 1982 was 102 Bq $^{90}Sr$ (kg Ca)$^{-1}$, i.e. the same as the 1979-1981 means.

Table 5.1.1. Strontium-90 in dried milk in 1982. (Unit: Bq (kg Ca)$^{-1}$)

| Month | Hjørring | Randers | Videbæk | Åbenrå | Nyborg | Ringsted | Nakskov | Mean |
|---|---|---|---|---|---|---|---|---|
| Jan | 167 | 161 | 186 | 156 | 51 | 74 | 75 | 124 |
| March | 164 | 129 | 134 | 129 | 74 | 76 | 103 | 115 |
| May | 112 | 105 | 132 | 135 | 66 | 59 | (70) | 97 |
| July | 109 | 106 | 109 | 97 | 52 | 69 | 54 | 85 |
| Sept | 118 | 96 | 108 | 99 | 56 | 74 | 72 | 89 |
| Nov | 134 | 99 | 149 | 116 | 63 | 78 | 72 | 102 |
| Mean Bq (kg Ca)$^{-1}$ | 134 | 116 | 136 | 122 | 60 | 71 | 74 | 102 |
| Mean pCi (g Ca)$^{-1}$ | 3.6 | 3.1 | 3.7 | 3.3 | 1.63 | 1.93 | 2.0 | 2.8 |

As 1 cubic meter of milk contains 1.2 kg Ca, the mean $^{90}Sr$ content in Danish milk produced in 1982 was 122 Bq m$^{-3}$ (3.4 pCi l$^{-1}$).
*Collected in February.

Figures in brackets were calculated from VAR3[12].

Table 5.1.2. Analysis of variance of ln Bq $^{90}Sr$ (kg Ca)$^{-1}$ in Danish dried milk in 1982 (from Table 5.1.1)

| Variation | SSD | f | $s^2$ | $v^2$ | p |
|---|---|---|---|---|---|
| Between months | 0.633 | 5 | 0.127 | 6.983 | > 99.95% |
| Between locations | 4.123 | 6 | 0.687 | 37.880 | > 99.95% |
| Remainder | 0.526 | 29 | 0.018 | | |

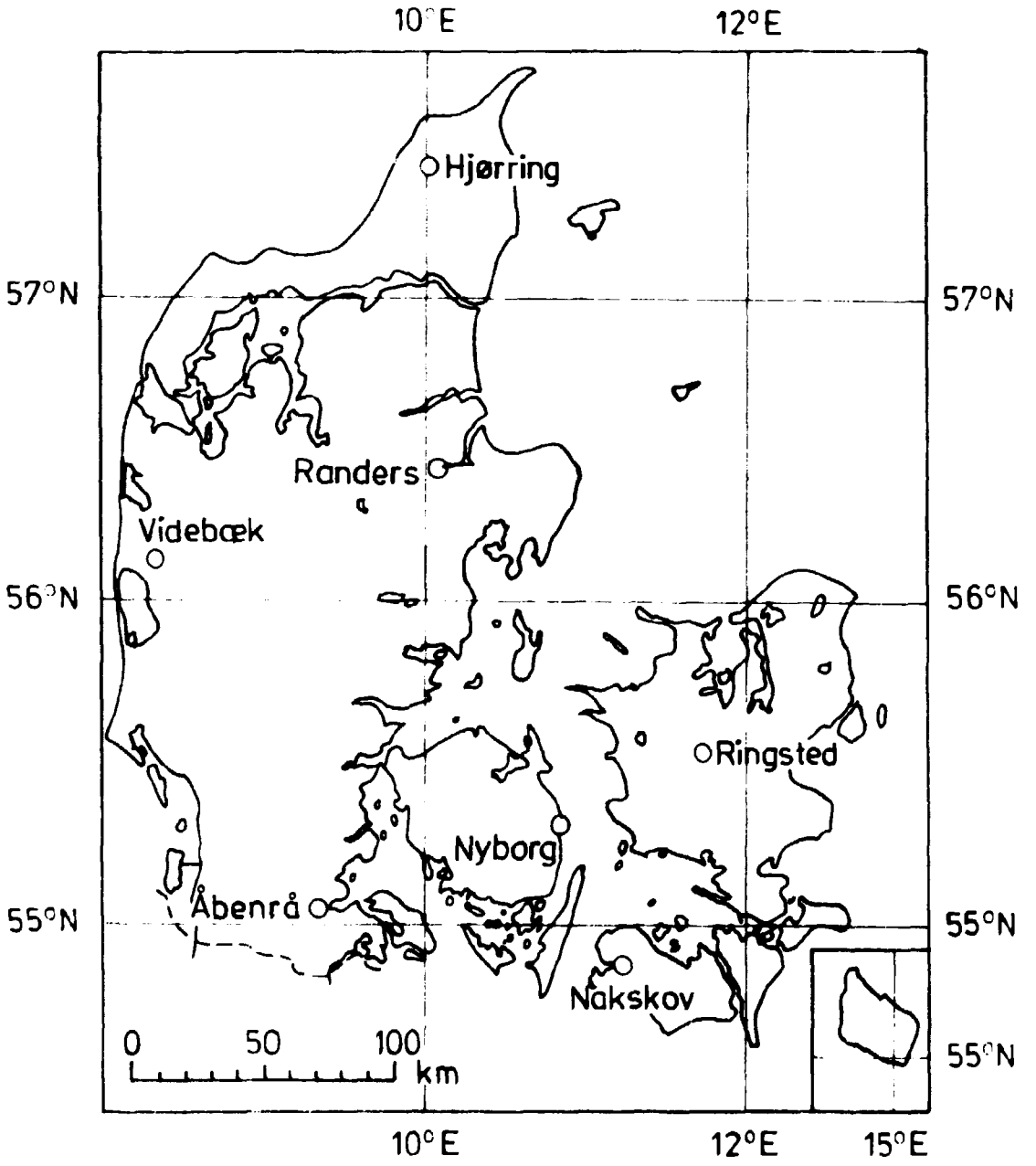


Fig. 5.1.1. Dried milk factories in Denmark.

Table 5.1.3 shows the results of the $^{137}Cs$ determinations and Table 5.1.4 the analysis of variance of the results. The $^{137}Cs$ mean level in 1982 was 63 Bq $^{137}Cs$ (kg K)$^{-1}$, or 77% of the 1981 level.

Table 5.1.3. Cesium-137 in Danish dried milk in 1982. (Unit: Bq (kg K)$^{-1}$)

| Month | Jutland | The Islands | Mean |
|---|---|---|---|
| January | 94 | 38 | 66 |
| February | 89 | 41 | 65 |
| March | 83 | 41 | 62 |
| April | 94 | 33 | 64 |
| May | 97 | 35 | 66 |
| June | 99 | 34 | 67 |
| July | 108 | 32 | 70 |
| August | 141 | 29 | 85 |
| September | 99 | 31 | 65 |
| October | 63 | 47 | 55 |
| November | 64 | 30 | 47 |
| December | 72 | 24 | 48 |
| Mean | 92 | 35 | 63 |
| Mean pCi (g K)$^{-1}$ | 2.5 | 0.93 | 1.71 |

As 1 cubic meter of milk contains approx. 1.66 kg K, the mean $^{137}Cs$ content in Danish milk produced in 1982 was estimated at 105 Bq m$^{-3}$ (2.8 pCi l$^{-1}$).

Table 5.1.4. Analysis of variance of ln Bq $^{137}Cs$ (kg K)$^{-1}$ in Danish dried milk in 1982 (from Table 5.1.3)

| Variation | SSD | f | $s^2$ | $v^2$ | P |
|---|---|---|---|---|---|
| Between months | 0.375 | 11 | 0.034 | 0.689 | - |
| Between locations | 5.777 | 1 | 5.777 | 116.580 | > 99.95% |
| Remainder | 0.545 | 11 | 0.050 | | |

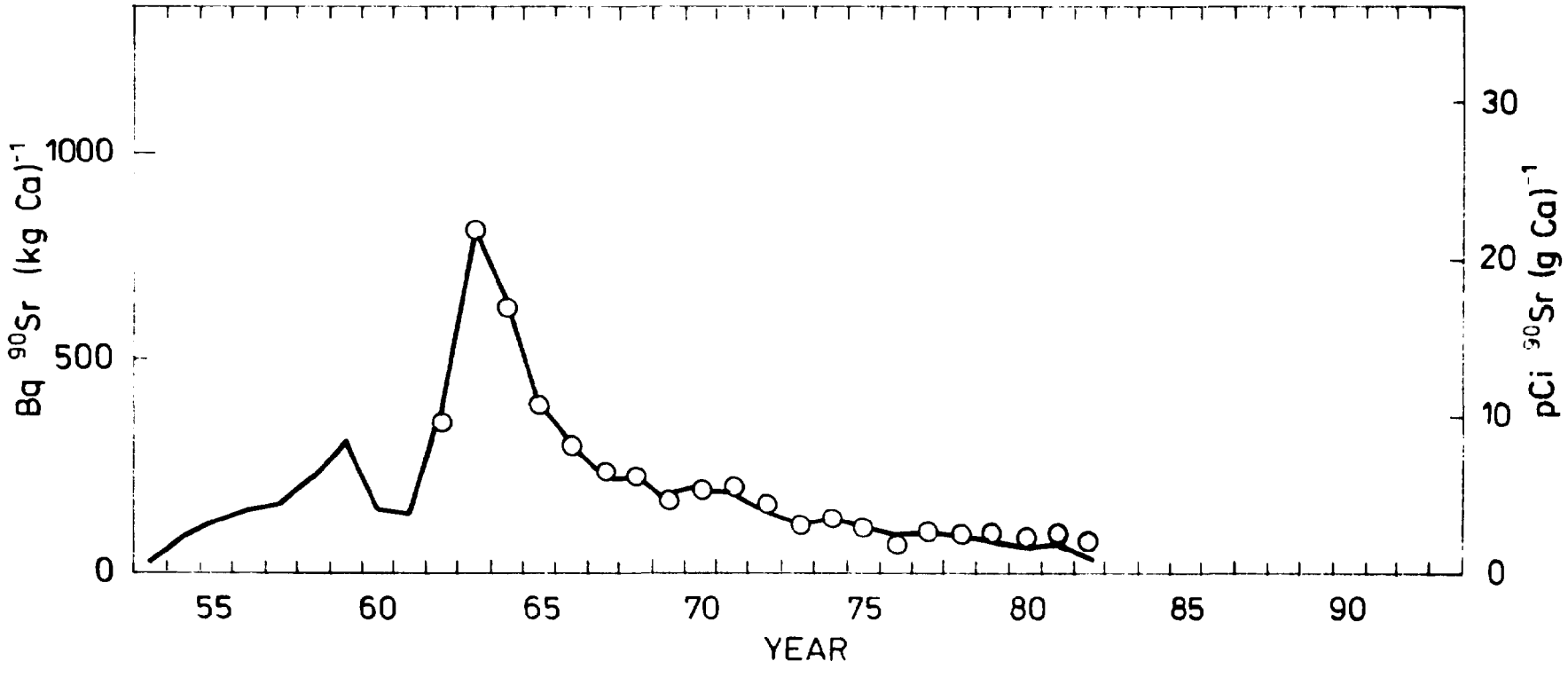


Fig. 5.1.2. Predicted (curve) and observed $^{90}$Sr/Ca levels in dried milk from the Islands (May 1962-April 1983).

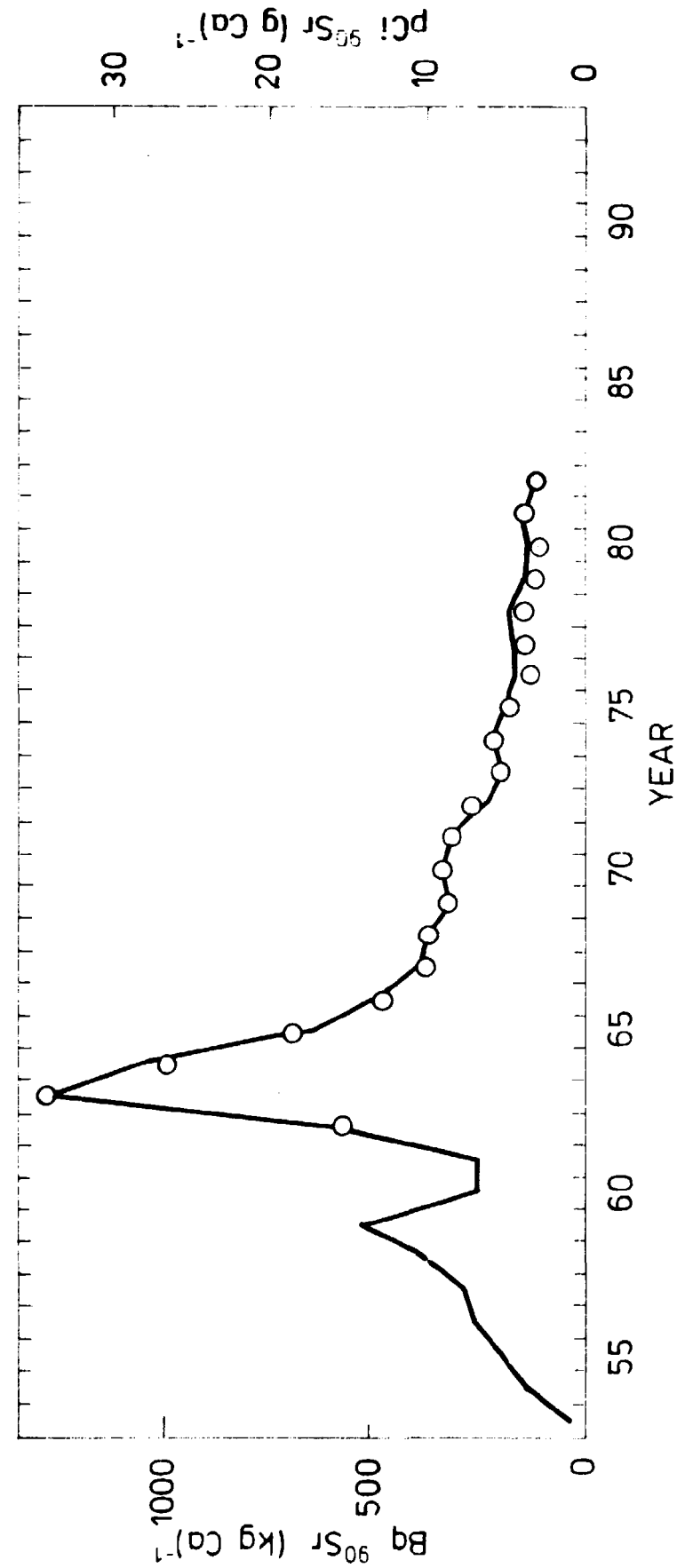


Fig. 5.1.3. Predicted (curve) and observed $^{90}$Sr/Ca levels in dried milk from Jutland (May 1962-April 1983).

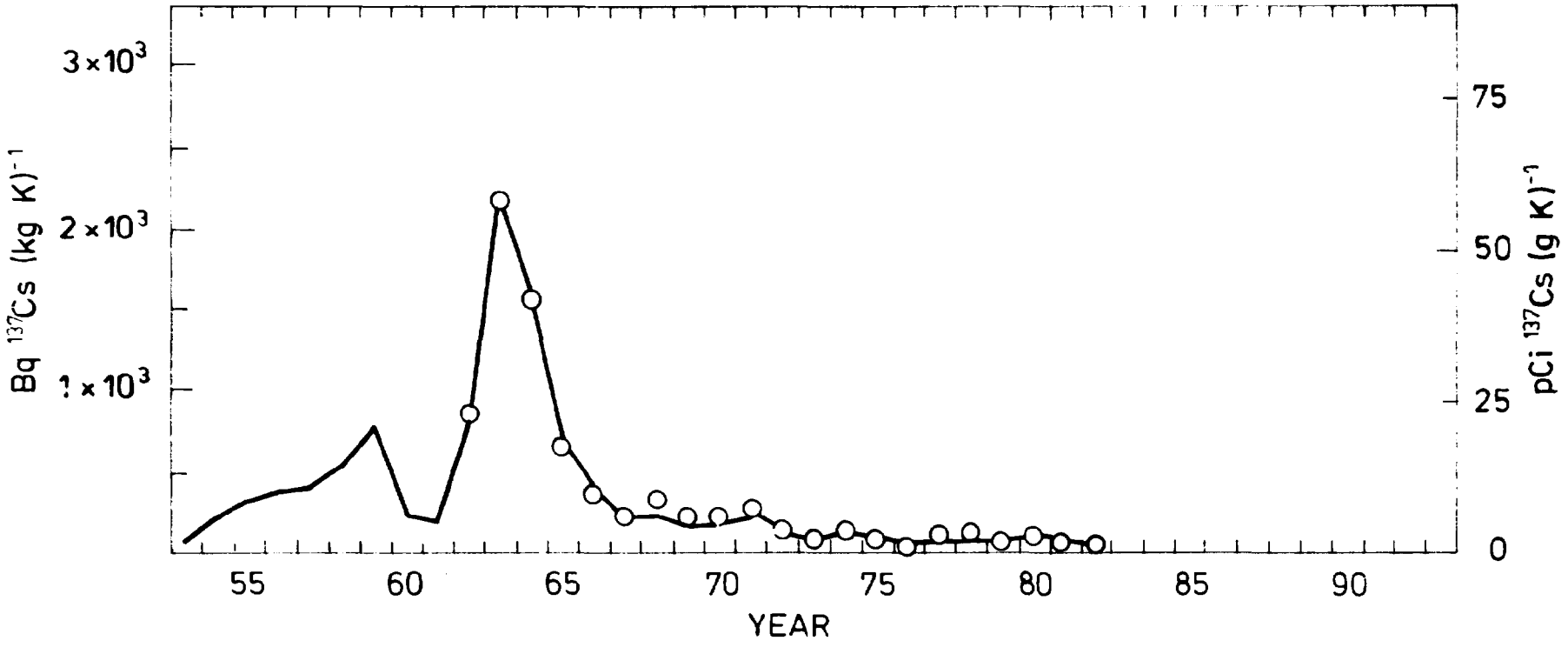


Fig. 5.1.4. Predicted (curve) and observed $^{137}$Cs/K levels in dried milk from the Islands (May 1962-April 1983).

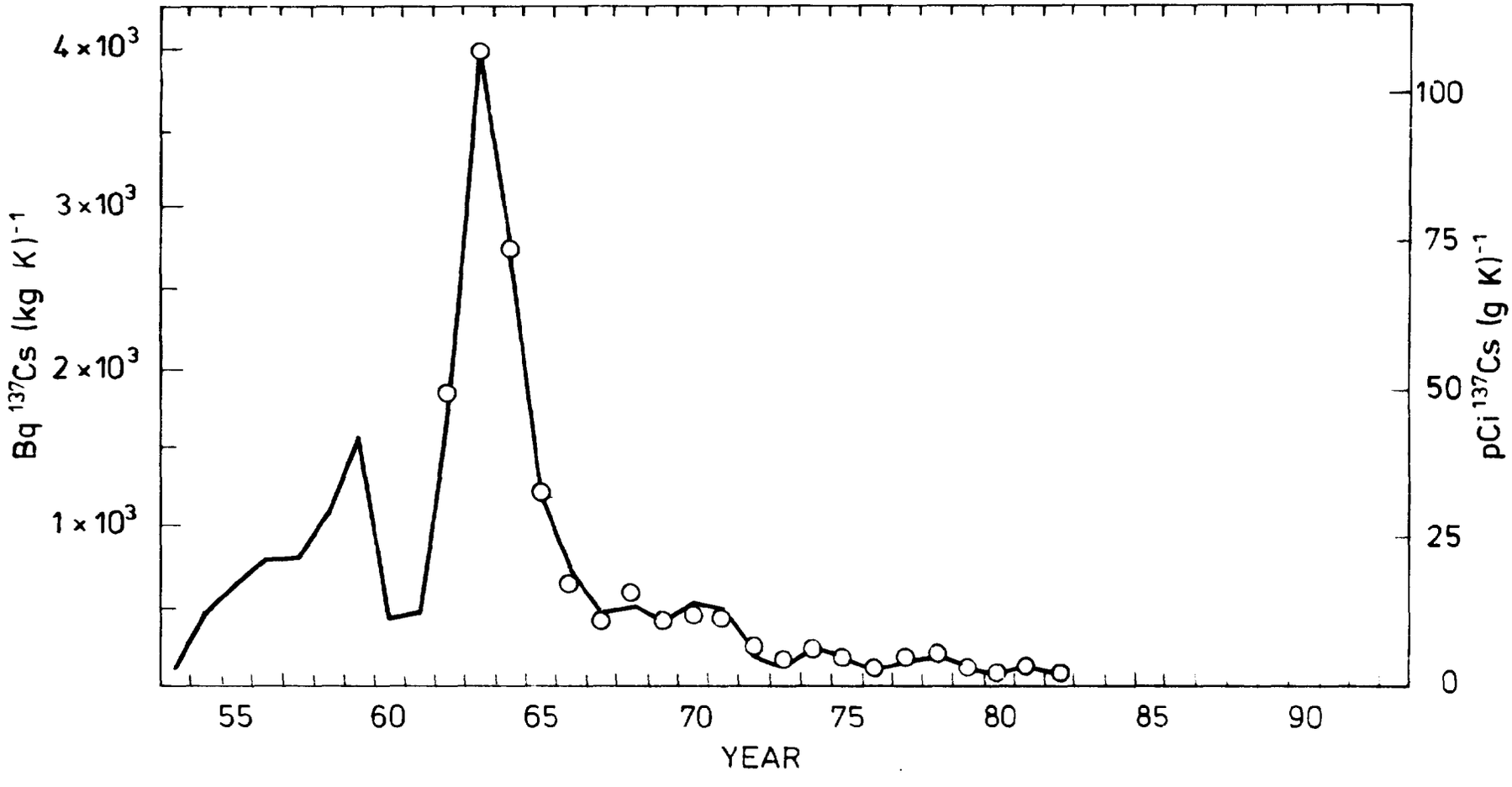


Fig. 5.1.5. Predicted (curve) and observed $^{137}Cs/K$ levels in dried milk from Jutland (May 1962-April 1983).

We found no significant variation in $^{137}Cs$ concentrations between months in 1982 (Table 5.1.4); this is unusual.

Figures 5.1.2-5.1.5 show the $^{90}Sr$ and $^{137}Cs$ levels in dried milk compared with the predicted values (cf. Appendix C). The observed $^{90}Sr$ levels in 1982 were 1.45 times the predicted, while the observed $^{137}Cs$ levels were 1.30 times the predicted ones (means of Jutland and the Islands).

## 5.2. Fresh milk

No samples in 1982.

## 5.3. Strontium-90 and Cesium-137 in grain from the entire country

As in previous years, grain samples were obtained from the State experimental farms (cf. Fig. 4.2). Strontium-90 was determined as previously (Risø Report No. 63[1]), and $^{137}Cs$ was measured on ashed samples by γ-spectrometry on a Ge(Li) detector. Due to the low $^{137}Cs$ concentrations the samples were combined in two sets of samples: one for Jutland and one from the Islands, each sample represented five farms.

Tables 5.3.1 and 5.3.2 show the measurements of $^{90}Sr$ in grain in 1982. Table 5.3.4 gives the analysis of variance of the Bq $^{90}Sr$ (kg Ca)$^{-1}$ figures and Table 5.3.3 that of the Bq $^{90}Sr$ kg$^{-1}$ grain figures.

Table 5.3.4 shows that the variations in Bq $^{90}Sr$ (kg Ca)$^{-1}$ between species and locations were significant. Oats showed the lowest Bq $^{90}Sr$ (kg Ca)$^{-1}$ levels. The Bq $^{90}Sr$ kg$^{-1}$ figures did not show any significant difference between species (cf. Table 5.3.3).

As in previous years, the variation with location was highly significant; the mean Bq $^{90}Sr$ kg$^{-1}$ level for grain from Jutland was 1.4 times that in eastern Denmark. The observed Bq $^{90}Sr$ kg$^{-1}$

Table 5.3.1. Strontium-90 in Danish grain in 1982. (Unit: Bq $kg^{-1}$)

| | Rye Winter | Barley | | Wheat | | Oats Spring |
|---|---|---|---|---|---|---|
| | | Spring | Winter | Winter | Spring | |
| Tylstrup | 0.91 | 0.73 | 0.73 | | | 0.80 |
| Ødum | | 0.32 | | | 0.35 | 0.58 |
| Askov | 0.55 | 0.92 | 0.69 | 0.66 | | |
| Borris | 0.80 | 0.76 | 0.84 | 0.62 | | 1.01 |
| St. Jyndevad | | 0.71 | 0.91 | 0.45 | | |
| Funen 5 | 1.18 | 0.36 | | 0.81 | | 0.78 |
| Tystofte | 0.29 | 0.68 | 0.39 | 0.64 | 0.48 | 0.82 |
| Ledreborg | 0.45 | 0.44 | 0.68 | 0.28 | 1.32 | 0.44 |
| Abed | | 0.25 | | 0.21 | | 0.26 |
| Bornholm 8 | 0.35 | 0.24 | 0.31 | 0.186 | | 0.29 |
| Mean Bq $kg^{-1}$ | Rye: 0.65 | Barley: 0.54 | | Wheat: 0.52 | | Oats: 0.62 |
| Mean pCi $kg^{-1}$ | Rye: 17.5 | Barley: 14.6 | | Wheat: 14.1 | | Oats: 16.8 |

Table 5.3.2. Strontium-90 in Danish grain in 1982. (Unit: Bq $(kg\ Ca)^{-1}$)

| | Rye Winter | Barley | | Wheat | | Oats Spring |
|---|---|---|---|---|---|---|
| | | Spring | Winter | Winter | Spring | |
| Tylstrup | 2700 | 2000 | 1710 | | | 1180 |
| Ødum | | 930 | | | 1540 | 780 |
| Askov | 1450 | 2200 | 1400 | 2000 | | |
| Borris | 2300 | 1960 | 2400 | 3000 | | 1360 |
| St. Jyndevad | | 1920 | 1710 | 1340 | | |
| Funen 5 | 2500 | 770 | | 2800 | | 1080 |
| Tystofte | 870 | 1430 | 740 | 1870 | 1200 | 810 |
| Ledreborg | 1010 | 1090 | 1320 | 1190 | 2700 | 460 |
| Abed | | 630 | | 720 | | 270 |
| Bornholm 8 | 1070 | 540 | 670 | 750 | | 350 |
| Mean Bq $(kg\ Ca)^{-1}$ | Rye: 1700 | Barley: 1290 | | Wheat: 1740 | | Oats: 790 |
| Mean pCi $(g\ Ca)^{-1}$ | Rye: 46 | Barley: 35 | | Wheat: 47 | | Oats: 21 |

Table 5.3.3. Analysis of variance of ln Bq $^{90}Sr$ $kg^{-1}$ in grain in 1982 (from Table 5.3.1)

| Variation | SSD | f | $s^2$ | $v^2$ | P |
|---|---|---|---|---|---|
| Between species | 0.233 | 3 | 0.078 | 0.779 | - |
| Between locations | 6.764 | 9 | 0.752 | 7.528 | > 99.95% |
| Spec. × loc. | 2.096 | 21 | 0.100 | 0.569 | - |
| Remainder | 1.580 | 9 | 0.176 | | |

Table 5.3.4. Analysis of variance of ln Bq $^{90}Sr$ (kg Ca)$^{-1}$ in grain in 1982 (from Table 5.3.2)

| Variation | SSD | f | $s^2$ | $v^2$ | P |
|---|---|---|---|---|---|
| Between species | 3.304 | 3 | 1.101 | 12.705 | > 99.95% |
| Between locations | 7.508 | 9 | 0.834 | 9.624 | > 99.95% |
| Spec. × loc. | 1.820 | 21 | 0.087 | 0.942 | - |
| Remainder | 0.828 | 9 | 0.092 | | |

levels in grain from 1982 were 1.64±1.28 (1 S.D.) times those predicted (cf. Appendix C).

Tables 5.3.5 and 5.3.6 show the measurements of $^{137}Cs$ in grain in 1982. The $^{137}Cs$ mean level in grain from 1982 was 0.15 times the level in 1981. The fallout in May-August 1982 was 0.13 times that of the fallout in May-August 1981.

Table 5.3.5. Cesium-137 in Danish grain in 1982 (Unit: Bq $kg^{-1}$)

| | Rye | Barley | Wheat | Oats |
|---|---|---|---|---|
| Jutland | 0.189 | 0.133 | 0.127 | 0.130 |
| The Islands | 0.163 | 0.079 | 0.077 | 0.080 |
| Mean Bq $kg^{-1}$ | 0.176 | 0.106 | 0.102 | 0.105 |
| Mean pCi $kg^{-1}$ | 4.8 | 2.9 | 2.8 | 2.8 |

Table 5.3.6. Cesium-137 in Danish grain in 1982. (Unit: Bq $(kg\ K)^{-1}$)

| | Rye | Barley | Wheat | Oats |
|---|---|---|---|---|
| Jutland | 48 | 28 | 44 | 36 |
| The Islands | 36 | 18.0 | 18.9 | 21 |
| Mean Bq $(kg\ K)^{-1}$ | 42 | 23 | 32 | 28 |
| Mean pCi $(g\ K)^{-1}$ | 1.14 | 0.63 | 0.86 | 0.77 |

The ANOVA's (Tables 5.3.7 and 5.3.8) showed probably significant variation between locations (Jutland = 1.53 × The Islands).

The observed pCi $^{137}Cs\ kg^{-1}$ levels in grain from 1982 were 1.23 ± 0.15 (1 S.D.) times those predicted (cf. Appendix C).

Table 5.3.7. Analysis of variance of ln Bq $^{137}Cs\ kg^{-1}$ in grain in 1982 (from Table 5.3.5)

| Variation | SSD | f | $s^2$ | $v^2$ | P |
|---|---|---|---|---|---|
| Between species | 0.507 | 3 | 0.169 | 8.516 | - |
| Between locations | 0.335 | 1 | 0.335 | 16.854 | > 95% |
| Remainder | 0.060 | 3 | 0.020 | | |

Table 5.3.8. Analysis of variance of ln Bq $^{137}Cs\ (kg\ K)^{-1}$ in grain in 1982 (from Table 5.3.6)

| Variation | SSD | f | $s^2$ | $v^2$ | P |
|---|---|---|---|---|---|
| Between species | 0.419 | 3 | 0.140 | 4.333 | - |
| Between locations | 0.584 | 1 | 0.584 | 18.100 | > 97.5% |
| Remainder | 0.097 | 3 | 0.032 | | |

## 5.4. Strontium-90 and Cesium-137 in bread from the entire country

In 1982, samples of white bread (75% extraction) and dark rye bread (100% extraction) were collected all over the country (cf. fig. 5.4) in June, and $^{90}Sr$ and $^{137}Cs$ were determined on pooled samples from Jutland and the Islands respectively. Samples from Copenhagen were analysed separately. The $^{137}Cs$ determinations were carried out on the ash by Ge(Li)γ-spectroscopy.

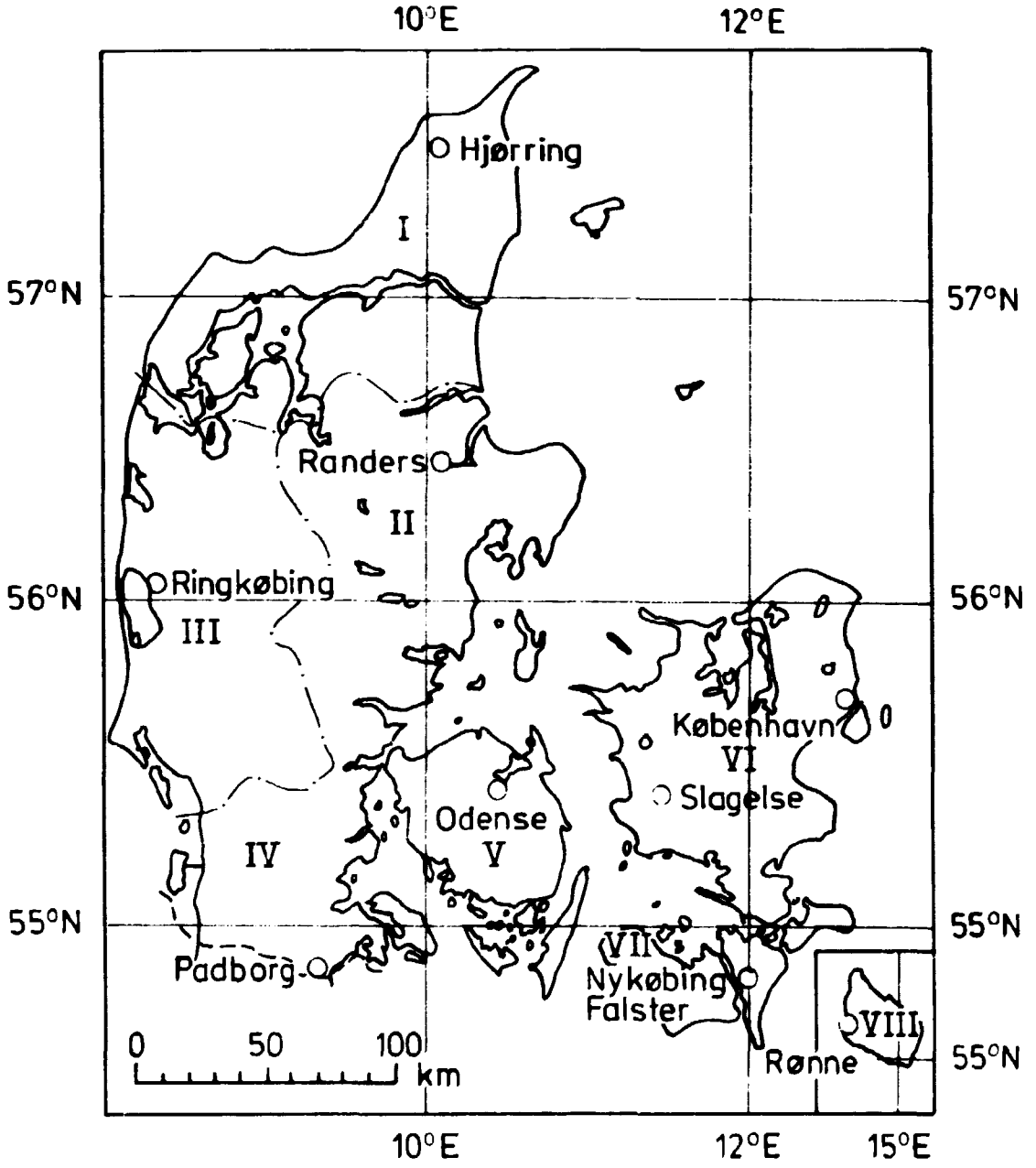


Fig. 5.4. Sample locations for bread and total diet.

Table 5.4.1. Strontium-90 and Cesium-137 in Danish bread collected in June 1982

| Zone | Rye bread | | | | White bread | | | |
|---|---|---|---|---|---|---|---|---|
| | Bq $^{90}Sr$ $kg^{-1}$ | Bq $^{90}Sr$ $(kg\ Ca)^{-1}$ | Bq $^{137}Cs$ $kg^{-1}$ | Bq $^{137}Cs$ $(kg\ K)^{-1}$ | Bq $^{90}Sr$ $kg^{-1}$ | Bq $^{90}Sr$ $(kg\ Ca)^{-1}$ | Bq $^{137}Cs$ $kg^{-1}$ | Bq $^{137}Cs$ $(kg\ K)^{-1}$ |
| Jutland | 0.60 | 220 | *0.74±0.04 | *230±18 | 0.26 | 151 | 0.171 | 138 |
| The Islands | 0.53 | 185 | **0.72±0.07 | **210±19 | 0.195 | 128 | 0.173 | 124 |
| Mean | 0.57 | 200 | 0.73 | 220 | 0.23 | 139 | 0.172 | 131 |
| Mean | 15.4 pCi $kg^{-1}$ | 5.5 pCi $(g\ Ca)^{-1}$ | 20 pCi $kg^{-1}$ | 5.9 pCi $(g\ K)^{-1}$ | 6.2 pCi $kg^{-1}$ | 3.8 pCi $(g\ Ca)^{-1}$ | 4.6 pCi $kg^{-1}$ | 3.4 pCi $(g\ K)^{-1}$ |
| Copenhagen | 0.47 | 400 | 0.71 | 240 | 0.34 | 156 | Included The Islands | Included The Islands |
| Population-weighted mean | 0.55 | 260 | 0.71 | 220 | 0.26 | 146 | 0.173 | 131 |

* Mean of Zones I-IV
**Mean of Zones V-VIII

Table 5.4.2. A comparison between $^{90}Sr$ and $^{137}Cs$ levels in bread and grain 1982

| Nuclide | Species | Bread activity in June 1982 calculated as grain in Bq $kg^{-1}$ (cf. text) | Activity in grain from harvest 1981[1)] Bq $kg^{-1}$ | "Bread"/grain ratio |
|---|---|---|---|---|
| $^{90}Sr$ | Wheat | 1.55 | 0.81 | 1.9 |
| | Rye | 0.77 | 1.10 | 0.7 |
| $^{137}Cs$ | Wheat | 0.46 | 0.55 | 0.8 |
| | Rye | 0.99 | 1.52 | 0.7 |

Table 5.4.1 shows the results. It is assumed that 1 kg flour yields approximately 1.35 kg bread[11)] and that wheat flour of 75% extraction contains 20% of the $^{90}Sr$ and 50% of the $^{137}Cs$ found in wheat grain[1)], while rye flour is 100% extraction. Hence we can compare the 1982 bread levels with the 1981 grain levels (cf. Table 5.4.2). The above assumptions for transfer of $^{137}Cs$ from grain to bread seem justified, however, the transfer of $^{90}Sr$ from wheat to white bread may be underestimated. This has in fact been envisaged in Risø-R-437 p. 86[21)] where it is predicted that the transfer will increase from 20 to 33%.

The mean ratios between observed and predicted bread values were 1.39 for $^{90}Sr$ and 1.02 for $^{137}Cs$ (cf. Appendix C).

## 5.5. Strontium-90 and Cesium-137 in potatoes from the entire country

The samples of potatoes were collected in September from ten of the State experimental farms (cf. fig. 4.2) and analysed for $^{90}Sr$ and $^{137}Cs$ ($\gamma$-spectroscopy of bulked samples of the ash).

Table 5.5.1 shows the $^{90}Sr$ and $^{137}Cs$ contents in potatoes. The mean contents for the country were 0.065 Bq $^{90}Sr$ $kg^{-1}$, or 1220 Bq $^{90}Sr$ (kg Ca)$^{-1}$, and 0.063 Bq $^{137}Cs$ $kg^{-1}$ or 16.1 Bq $^{137}Cs$ (kg K)$^{-1}$. The $^{90}Sr$ levels were 85% of those in 1981, and the $^{137}Cs$ concentrations were 57% of the in 1981 values.

The mean ratio between observed and predicted $^{90}Sr$ concentrations in potatoes was 0.65 and for $^{137}Cs$ we found 1.32 (cf. Appendix C).

Table 5.5.1. Strontium-90 and Cesium-137 in Danish potatoes in 1982

| | Bq $^{90}Sr$ $kg^{-1}$ | Bq $^{90}Sr$ (kg Ca)$^{-1}$ | Bq $^{137}Cs$ $kg^{-1}$ | Bq $^{137}Cs$ (kg K)$^{-1}$ |
|---|---|---|---|---|
| Tylstrup | 0.050 | 1320 | | |
| Borris | 0.078 | 870 | | |
| Ødum | 0.090 | 970 | 0.106 | 28 |
| Askov | 0.078 | 2400 | | |
| St. Jyndevad | 0.054 | 940 | | |
| Funen | 0.047 | 700 | | |
| Tystofte | 0.059 | 940 | | |
| Sedreborg | 0.100 | 1740 | 0.019 A | 4.3 A |
| Abed | 0.045 | 780 | | |
| Rønne | 0.052 | 1460 | | |
| Mean | 0.065 | 1220 | 0.063 | 16.1 |
| Mean | 1.77 pCi $kg^{-1}$ | 33 pCi (g Ca)$^{-1}$ | 1.70 pCi $kg^{-1}$ | 0.44 pCi (g K)$^{-1}$ |

## 5.6. Strontium-90 and Cesium-137 in vegetables and fruits from the entire country

In 1982, as in previous years, vegetables and fruit were collected in the autumn from eight larger provincial towns, one in each of the eight zones (cf. fig. 5.4).

The γ-measurements were performed on bulked ash samples representing the entire country (cf. Table 5.6.2).

Table 5.6.3 shows a calculation of the mean contents of $^{90}Sr$ and $^{137}Cs$ in Danish vegetables collected in 1982. The $^{90}Sr$ levels are a little lower than those in 1978-1981.

The $^{137}Cs$ concentrations in 1982 were approximately 40% of those in 1981.

Table 5.6.1. Strontium-90 in vegetables and fruits collected in September 1982

| | White Cabbage | | Carrot | | Apples | |
|---|---|---|---|---|---|---|
| | Bq $kg^{-1}$ | Bq (kg Ca)$^{-1}$ | Bq $kg^{-1}$ | Bq (kg Ca)$^{-1}$ | Bq $kg^{-1}$ | Bq (kg Ca)$^{-1}$ |
| Jutland | 0.46 | 960 | 0.55 | 2200 | 0.021 | 690 |
| The Islands | 0.24 | 440 | 0.33 | 890 | 0.025 | 590 |
| Mean | 0.35 | 700 | 0.44 | 1560 | 0.023 | 640 |
| Mean | 9.4 pCi $kg^{-1}$ | 18.9 pCi (g Ca)$^{-1}$ | 11.9 pCi $kg^{-1}$ | 42 pCi (g Ca)$^{-1}$ | 0.62 pCi $kg^{-1}$ | 17.3 pCi (g Ca)$^{-1}$ |

Table 5.6.2. Cesium-137 in vegetables and fruits collected in September 1982

| | White Cabbage | | Carrot | | Apples | |
|---|---|---|---|---|---|---|
| | Bq $kg^{-1}$ | Bq (kg K)$^{-1}$ | Bq $kg^{-1}$ | Bq (kg K)$^{-1}$ | Bq $kg^{-1}$ | Bq (kg K)$^{-1}$ |
| Jutland | 0.029 | 11.8 | 0.062 | 31 | 0.054 | 48 |
| The Islands | 0.027 | 13.8 | 0.014 A | 6.5 A | 0.035 | 30 |
| Mean | 0.028 | 12.8 | 0.038 | 19.0 | 0.044 | 39 |
| Mean | 0.76 pCi $kg^{-1}$ | 0.34 pCi (g K)$^{-1}$ | 1.03 pCi $kg^{-1}$ | 0.51 pCi (g K)$^{-1}$ | 1.19 pCi $kg^{-1}$ | 1.06 pCi (g K)$^{-1}$ |

Table 5.6.3. Calculated $^{90}Sr$ and $^{137}Cs$ mean levels in vegetables in 1982

| Daily intake in g | Bq $^{90}Sr$ $kg^{-1}$ | Bq $^{90}Sr$ (kg Ca)$^{-1}$ | Bq $^{137}Cs$ $kg^{-1}$ | Bq $^{137}Cs$ (kg K)$^{-1}$ |
|---|---|---|---|---|
| 50 leaf vegetables (cabbage) | 0.35 | 700 | 0.028 | 12.8 |
| 30 root vegetables (carrot) | 0.44 | 1560 | 0.038 | 19.0 |
| 40 pea (1981 data) | 0.19 | 700 | 0.095 | 6 |
| 120 | 0.32 | 915 | 0.053 | 12 |

The 1982 levels in Danish fruit were calculated from apples and the mean levels in Danish fruit were thus 0.023 Bq $^{90}Sr$ $kg^{-1}$ and 0.044 Bq $^{137}Cs$ $kg^{-1}$. The observed Bq $^{90}Sr$ $kg^{-1}$ levels in vegetables and fruit in 1982 were 1.25±0.34 (1 S.D.) times those predicted (cf. Appendix C). In the case of $^{137}Cs$, the observed values were 1.69±1.30 times the predicted ones.

## 5.7. Strontium-90 and Cesium-137 in total diet from the entire country

In 1982 total-food samples representing an average Danish diet according to E. Hoff-Jørgensen (cf. Appendix B in Risø Report No. 63[1]) were collected from eight towns each representing one of the eight zones (cf. Fig. 5.2.1) and from Copenhagen. The sampling took place as previously in June and December.

Tables 5.7.1 and 5.7.2 show the results. The $^{90}Sr$ diet levels from Jutland were 19% higher than those from the Islands, and the $^{137}Cs$ levels were 15% higher.

Figure 5.7.1 show the zone mean Bq $^{90}Sr$ (kg Ca)$^{-1}$ levels (not population-weighted) in total diet compared with the predicted

Table 5.7.1. Strontium-90 and Cesium-137 in Danish total diet collected in June 1982

| Zone | Bq $^{90}Sr$ (kg Ca)$^{-1}$ | Bq $^{90}Sr$ $d^{-1}$ | g Ca $d^{-1}$ | Bq $^{137}Cs$ (kg K)$^{-1}$ | Bq $^{137}Cs$ $d^{-1}$ |
|---|---|---|---|---|---|
| I: N. Jutland | 203± 0 | 0.36±0.00 | 1.78±0.00 | 124 | 0.48 |
| II: E. Jutland | 139± 1 | 0.22±0.00 | 1.56±0.00 | 123 | 0.48 |
| III: W. Jutland | 147±12 | 0.25±0.02 | 1.67±0.01 | 120 | 0.47 |
| IV: S. Jutland | 179± 4 | 0.28±0.01 | 1.58±0.00 | 115 | 0.42 |
| V: Funen | 161± 3 | 0.24±0.00 | 1.48±0.01 | 133 | 0.50 |
| VI: Zealand | 134± 0 | 0.22±0.00 | 1.64±0.01 | 95 | 0.37 |
| VII: Lolland-Falster | 122± 5 | 0.20±0.01 | 1.64±0.00 | 90 | 0.36 |
| VIII: Bornholm | 143± 4 | 0.20±0.01 | 1.42±0.01 | 79 | 0.33 |
| Mean | 154 | 0.25 | 1.60 | 110 | 0.43 |
| Mean | 4.2 S.U. | 6.8 pCi $d^{-1}$ | | 3.0 M.U. | 11.5 pCi $d^{-1}$ |
| Copenhagen | 178± 6 | 0.27±0.01 | 1.52±0.00 | 122 | 0.45 |
| Population-weighted mean | 160 | 0.26 | 1.60 | 118 | 0.45 |
| Relative error due to analysis | 5% | 5% | | | |

Table 5.7.2. Strontium-90 and Cesium-137 in Danish total diet collected in December 1982

| Zone | Bq $^{90}Sr$ (kg Ca)$^{-1}$ | Bq $^{90}Sr$ d$^{-1}$ | g Ca d$^{-1}$ | Bq $^{137}Cs$ (kg K)$^{-1}$ | Bq $^{137}Cs$ d$^{-1}$ |
|---|---|---|---|---|---|
| I: N. Jutland | 142±14 | 0.23 ±0.02 | 1.64±0.00 | 109 | 0.41 |
| II: E. Jutland | 139± 3 | 0.21 ±0.00 | 1.50±0.00 | 72 | 0.28 |
| III: W. Jutland | 167± 6 | 0.28 ±0.01 | 1.66±0.00 | 78 | 0.30 |
| IV: S. Jutland | 126± 4 | 0.197±0.006 | 1.57±0.01 | 102 | 0.38 |
| V: Funen | 118± 3 | 0.20 ±0.01 | 1.69±0.00 | 104 | 0.38 |
| VI: Zealand | *120±10* | *0.195±0.015* | *1.62±0.02* | *53* | *0.21* |
| VII: Lolland-Falster | 139± 9 | 0.23 ±0.01 | 1.63±0.00 | 108 | 0.38 |
| VIII: Bornholm | 140± 0 | 0.21 ±0.00 | 1.49±0.00 | 70 | 0.27 |
| Mean | 136 | 0.22 | 1.60 | 87 | 0.33 |
| Mean | 3.7 S.U. | 5.9 pCi d$^{-1}$ | | 2.4 M.U. | 8.9 pCi d$^{-1}$ |
| Copenhagen | 126± 1 | 0.20 ±0.00 | 1.60±0.01 | 64 | 0.24 |
| Population-weighted mean | 134 | 0.22 | 1.61 | 77 | 0.29 |
| Relative error due to analysis | 7% | 7% | | | |

values (cf. Appendix C), the observed value was 0.89 times that predicted.

The $^{90}Sr$ 1982 levels (mean of June and December values) in the total diet were nearly equal to the 1981 levels, and so were the $^{137}Cs$ levels.

From the total-diet sampling it is possible to estimate the mean levels of $^{90}Sr$ and $^{137}Cs$ in the Danish diet in 1982. For the period January-March 1982, the $^{90}Sr$ level in the total diet is assumed to have been equal to that measured in December 1981, Risø Report No. 447[1]. For the period April-September we assume the level to have corresponded to that measured in June 1982. The December 1982 figures are taken to represent the last three months of the year. Hence the mean content in the total diet in 1982 was 152 Bq $^{90}Sr$ (kg Ca)$^{-1}$, or 0.25 Bq $^{90}Sr$ (day)$^{-1}$.

Similarly, the $^{137}Cs$ content in the Danish diet in 1982 was estimated to be 0.40 Bq $^{137}Cs$ (day)$^{-1}$ or 106 Bq $^{137}Cs$ (kg K)$^{-1}$. The observed $^{137}Cs$ fallout level in total diet was 1.57 times that predicted (cf. Appendix C.2) (corrected for $^{137}Cs$ from Sellafield cf. 5.8.2).

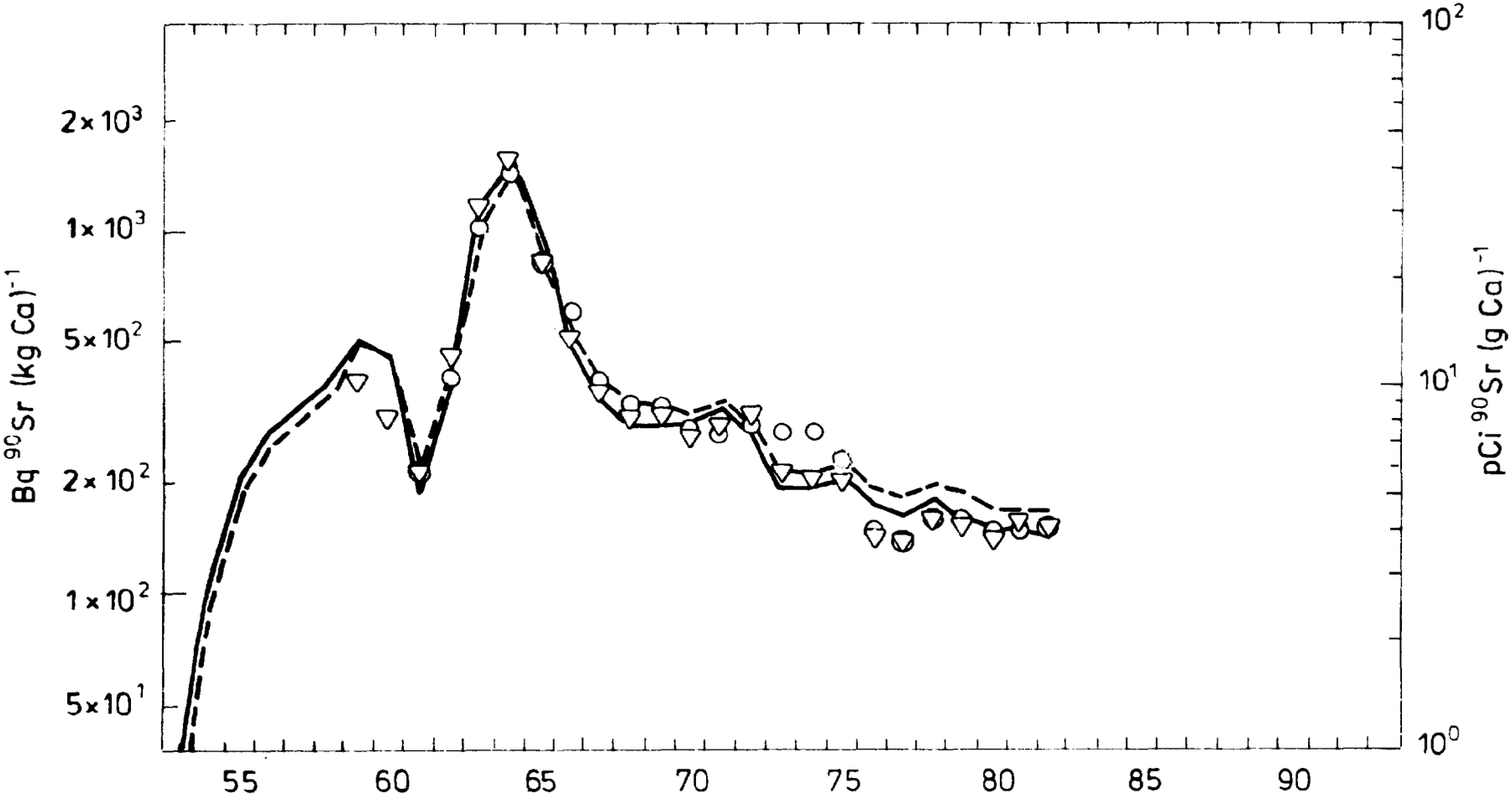


Fig. 5.7.1. Predicted and observed $^{90}$Sr levels in the Danish total diet. The dotted curve represents the predicted values for "Diet C" (cf. Tables 5.7.1 and 5.7.2) and the circles are the corresponding observed values. The unbroken curve represents the predicted values for "Diet P" (cf. Table 5.9.3), and the triangles the corresponding observed values.

## 5.8. Strontium-90 and Cesium-137 in miscellaneous foodstuffs

### 5.8.1. Strontium-90 and Cesium-137 in meat

Pork and beef samples were collected in Copenhagen in three large shops in March and September. Table 5.8.1 shows the results. As compared with 1981, the mean levels were nearly unchanged.

The mean ratio between observed and predicted (cf. Appendix C.2) $^{137}Cs$ levels in meat was 1.81 and for $^{90}Sr$ the mean ratio was 1.06. As observed values we used those from September 1982, as the meat models cover the period April$_{(i)}$-March$_{(i+1)}$.

Table 5.8.1. Strontium-90 and Cesium-137 in Danish meat collected in Copenhagen in 1982

| | Pork | | | | Beef | | | |
|---|---|---|---|---|---|---|---|---|
| Month | Bq $^{90}Sr$ $kg^{-1}$ | Bq $^{90}Sr$ (kg Ca)$^{-1}$ | Bq $^{137}Cs$ $kg^{-1}$ | Bq $^{137}Cs$ (kg K)$^{-1}$ | Bq $^{90}Sr$ $kg^{-1}$ | Bq $^{90}Sr$ (kg Ca)$^{-1}$ | Bq $^{137}Cs$ $kg^{-1}$ | Bq $^{137}Cs$ (kg K)$^{-1}$ |
| March | 0.0078 | 67 | 0.40 | 139 | 0.0177 | 179 | 0.44 | 136 |
| Sept | 0.0168 | 159 | 0.31 | 89 | 0.055 | 520 | 0.40 | 100 |
| Mean | 0.0123 | 113 | 0.36 | 114 | 0.036 | 350 | 0.42 | 118 |
| Mean | 0.33 pCi $kg^{-1}$ | 3.0 S.U. | 9.6 pCi $kg^{-1}$ | 3.1 M.U. | 0.98 pCi $kg^{-1}$ | 9.4 S.U. | 11.4 pCi $kg^{-1}$ | 3.2 M.U. |

### 5.8.2. Strontium-90, Cesium-137 and Cesium-134 in fish

Fish samples were collected in the North Sea and in inner Danish waters. Tables 5.8.2.1 and 5.8.2.2 show the results. The mean levels of the two samplings were 0.022±0.003 (1 S.E., N = 6) Bq $^{90}Sr$ $kg^{-1}$ and 4.2±0.8 Bq $^{137}Cs$ $kg^{-1}$ (0.59 pCi $^{90}Sr$ $kg^{-1}$ and 113 pCi $^{137}Cs$ $kg^{-1}$). In the fish from the North Sea the $^{134}Cs/^{137}Cs$ mean ratio was 0.037 while it was 0.026 for fish from inner Danish waters.

Earlier we have estimated the contribution of $^{137}Cs$ in the Danish fish catch as 85% (Risø Report No 469[1] p 86). This estimate was based upon the assumption that fallout contributed 5% and 30% to the total concentrations of $^{137}Cs$ in the North Sea and Danish Straits, respectively. We may, however, use another approach for calculating the contributions from Sellafield.

Table 5.8.2.1. Strontium-90, Cesium-137 and Cesium-134 in fish from the North Sea purchased in Ringkøbing in October 1982

| Species | Bq $^{90}Sr$ $kg^{-1}$ | Bq $^{90}Sr$ (kg Ca)$^{-1}$ | Bq $^{137}Cs$ $kg^{-1}$ | Bq $^{137}Cs$ (kg K)$^{-1}$ | $^{134}Cs/^{137}Cs$ |
|---|---|---|---|---|---|
| Cod | 0.030 | 38 (12.9) | 3.3 | 790 | 0.032 |
| Plaice | 0.022 | 35 (15.7) | 1.23 | 390 | 0.050 |
| Herring | 0.0191 | 41 ( 7.2) | 4.4 | 1360 | 0.030 |

Bone levels are shown in brackets.

Table 5.8.2.2. Strontium-90, Cesium-137 and Cesium-134 in fish from inner Danish waters purchased in Hundested in September 1982

| Species | Bq $^{90}Sr$ $kg^{-1}$ | Bq $^{90}Sr$ (kg Ca)$^{-1}$ | Bq $^{137}Cs$ $kg^{-1}$ | Bq $^{137}Cs$ (kg K)$^{-1}$ | $^{134}Cs/^{137}Cs$ |
|---|---|---|---|---|---|
| Cod | 0.025 | 35 (14.1) | 7.3 | 1850 | 0.025 |
| Plaice | 0.031 | 35 (22 ) | 4.3 | 1020 | 0.022 |
| Herring | 0.0077 | 18.7 ( 7.3) | 4.5 | 1070 | 0.030 |

Bone levels are shown in brackets.

If the transit time to the Danish Straits is 4 years (cf. 4.4) and to the North Sea 3 years, we may take the $^{134}Cs/^{137}Cs$ ratios in the Sellafield discharges from 1978 (0.0987; in 1982: 0.0282) and from 1979 (0.0919; in 1982: 0.0359) and compare them with those in fish. The ratios for fish from the North Sea (Table 5.8.2.1) agreed with the expected ratio, while those of fish from the Danish Straits (Table 5.8.2.2) were 90% of the expected value. The samples from the Sound (Table 5.8.2.4) showed ratios that were 85% of the expected value. If we assume that the catches of fish consumed by the Danish population was nearly the same in the North Sea and the Danish Straits, we may conclude that Sellafield contributed with 90-95% of the total $^{137}Cs$ intake from fish consumption in Denmark in 1982. This estimate is a little higher than that from previous years. As our best estimate for 1982 we shall use 90%.

The dose from Sellafield to the Danish population then becomes $4.2 \times 0.9 \times 5 \times 10^6 \times 10.9 \times 0.05 \times (4 \times 10^6)^{-1} = 2.6$ manSv ($5 \times 10^6$ population size, 10.9: annual per capita fish consumption in kg, 0.05 Sievert pr $4 \times 10^6$ Bq $^{137}Cs$).

As in 1980 and 1981[1] we measured a number of garpikes caught in May. The isotopic concentration in flesh was 7.0 Bq $^{137}Cs$ $kg^{-1}$, i.e. nearly half of the 1981 value.

Contrary to the observations in 1980 and 1981, the 1982 garpike sample showed no evidence of a short circuiting of the transport of radiocesium from Sellafield to Danish waters. The reason may be that the 1982 sample was obtained too late, and that the fish therefore had stayed too long in the Danish Straits to preserve their higher $^{137}Cs$ concentrations received in British waters.

Table 5.8.2.5 shows radionuclide concentrations in Mytilus edulis from Danish waters. The $^{137}Cs$ mean content in flesh was 0.32 Bq $kg^{-1}$ fresh weight. This is half of the level observed in 1981. Cobalt-60 was also detectable in mussels. The mean concentration was 0.063 Bq $^{60}Co$ $kg^{-1}$ fresh weight.

Table 5.8.2.3. Cesium-137 and Cesium-134 in garpike caught in the Cattegat May 13, 1982

| Sample | Bq $^{137}Cs$ $kg^{-1}$ | Bq $^{137}Cs$ (kg K)$^{-1}$ | $^{134}Cs/^{137}Cs$ |
|---|---|---|---|
| Meat | 7.0 | 1640 | 0.029 |
| Liver | 7.9 | 1780 | - |

The liver was also analysed for $^{239,240}Pu$ and $^{241}Am$ but the levels were below our detection limits.

Table 5.8.2.4. Gamma-emitting radionuclides in fish from The Sound in 1982. (Unit: Bq $kg^{-1}$)

| Sample | Date | Location | | $^{137}Cs$ | $^{134}Cs$ | $^{60}Co$ | $^{65}Zn$ |
|---|---|---|---|---|---|---|---|
| Dab meat | 21/5 | 55°49'N | 12°48'E | 2.4 | 0.058 | 0.022 A | |
| Dab bone | " | " | " | 0.24 A | | | |
| Dab total | " | " | " | 2.6 | 0.062 | 0.055 | 0.057 A |
| Dab meat | 21/6 | 55°53'N | 12°42'E | 2.7 | 0.066 | 0.020 A | |
| Cod meat | " | " | " | 7.0 | 0.155 | < 0.016 | |
| Cod bone | " | " | " | B.D.L. | | | |

Table 5.8.2.5. Gamma-emitting radionuclides in Mytilus edulis flesh collected in inner Danish waters in 1982. (Unit: Bq $kg^{-1}$ dry weight)

| Location | Skagen | 54°58'N 14°44'E | 57°39'N 11°41'E* |
|---|---|---|---|
| Date | 11/7 | 27/6 | 10/7 |
| Weight fresh/dry | 7.19 | 9.37 | 6.90 |
| Depth in m | 0.5 | 10 | 0.5 |
| $^{60}Co$ | 0.48 | 0.56 A | ↑ |
| $^{106}Ru$ | 3.3 A | | |
| $^{137}Cs$ | 3.2 | 1.74 | B.D.L. |
| $^{144}Ce$ | 1.2 A | 7.0 | |
| $^{226}Ra$ | 0.92 | 2.6 | |
| $^{228}Ra$ | 1.5 A | | ↓ |

*Only 14 g fresh.

## 5.8.3. Strontium-90 and Cesium-137 in eggs

Eggs were collected in Copenhagen in 1982. They contained 0.030 Bq $^{90}Sr$ $kg^{-1}$ (59 Bq $^{90}Sr$ (kg Ca)$^{-1}$) and 0.033 Bq $^{137}Cs$ $kg^{-1}$ (24 Bq $^{137}Cs$ (kg K)$^{-1}$). The predicted values for eggs (cf. Appendix C) were 0.014 Bq $^{90}Sr$ $kg^{-1}$ and 0.053 Bq $^{137}Cs$ $kg^{-1}$.

## 5.8.4 Strontium-90 and cesium-137 in various vegetable foods

As compared with the last sampling in 1980 the amounts of $^{90}Sr$ and $^{137}Cs$ in coffee were a little lower while the concentrations in tea were higher. Levels in orange and banana had also increased since our 1980 sampling. Tne $^{90}Sr$ content in rice was surprisingly high as compared with previous years, while the $^{137}Cs$ concentration was similar to that in 1980. The $^{90}Sr$ and $^{137}Cs$ levels in oats were equal to those in grits from the 1981 harvest (cf. Risø Report 469[1] p. 89-90).

Table 5.8.4. Strontium-90 and Cesium-137 in imported vegetable products collected in Copenhagen in November 1982

| Sample | Bq $^{90}Sr$ $kg^{-1}$ | Bq $^{90}Sr$ (kg Ca)$^{-1}$ | Bq $^{137}Cs$ $kg^{-1}$ | Bq $^{137}Cs$ (kg K)$^{-1}$ |
|---|---|---|---|---|
| Coffee (as drunk) | 0.38 | 92 | 0.55 | 28 |
| Tea (as drunk) | 1.85 | 700 | 6.5 | 410 |
| Orange | 0.169 | 410 | 0.048 | 31 |
| Banana | 0.094 | 430 | B.D.L. | B.D.L. |
| Rice | 0.54 | 1480 | 0.036 A | 28 A |
| Hazelnuts (Danish) | 0.079 | 68 | 0.82 | 92 |
| Oats (Danish) | 0.64 | 155 | 0.49 | 134 |

## 5.9. Estimate of the mean contents of $^{90}Sr$ and $^{137}Cs$ in the human diet in Denmark in 1982

### 5.9.1. The annual quantities

The annual quantities are calculated by multiplication of the daily quantities by 365 (as stated by E. Hoff-Jørgensen, cf. Risø Report No. 63, Table B[1]).

### 5.9.2. Milk and cream

The $^{90}Sr$ and $^{137}Cs$ contents per kg milk were calculated from the annual mean values for dried milk (cf. Tables 5.1.1 and 5.1.3). 1 kg ~ 1 l milk, containing approximately 1.2 g Ca and 1.66 g K. Hence the mean contents in milk were 0.122 Bq $^{90}Sr$ $kg^{-1}$ and 0.105 Bq $^{137}Cs$ $kg^{-1}$.

### 5.9.3. Cheese

One kg of cheese contains approximately 8.5 g Ca and 1.2 g K. The $^{90}Sr$ and $^{137}Cs$ contents in cheese were calculated from these figures and from the $^{90}Sr$/Ca and $^{137}Cs$/K ratios in dried milk (cf. Tables 5.1.1 and 5.1.3). One kg of cheese appeared to contain 0.87 Bq $^{90}Sr$ and 0.076 Bq $^{137}Cs$.

## 5.9.4. Grain products

Tables 5.9.1 and 5.9.2 show the estimates of $^{90}Sr$ and $^{137}Cs$, respectively, in grain products consumed in 1982. From these tables, the activity levels in grain products were estimated at 0.47 Bq $^{90}Sr$ $kg^{-1}$ and 0.57 Bq $^{137}Cs$ $kg^{-1}$.

Table 5.9.1. Estimate of the $^{90}Sr$ content in grain products consumed per caput in 1982

| Type | Fraction from harvest 1981 | | | Fraction from harvest 1982 | | | Total Bq |
|---|---|---|---|---|---|---|---|
| | kg flour | Bq $kg^{-1}$ | Bq | kg flour | Bq $kg^{-1}$ | Bq | |
| Rye flour 100% extraction | 21.9 | 1.10 | 24.09 | 7.3 | 0.65 | 4.75 | 28.84 |
| Wheat flour 75% extraction | 32.9 | 0.16 | 5.26 | 10.9 | 0.10 | 1.09 | 7.16 |
| Grits | 5.5 | 0.35 | 1.93 | 1.8 | 0.20 | 0.36 | 2.29 |
| Total | 60.3 | 0.52 | 31.28 | 20.0 | 0.31 | 6.20 | 37.48 |

Table 5.9.2. Estimate of the $^{137}Cs$ content in grain products consumed per caput in 1982

| Type | Fraction from harvest 1981 | | | Fraction from harvest 1982 | | | Total Bq |
|---|---|---|---|---|---|---|---|
| | kg flour | Bq $kg^{-1}$ | Bq | kg flour | Bq $kg^{-1}$ | Bq | |
| Rye flour 100% extraction | 21.9 | 1.52 | 33.29 | 7.3 | 0.18 | 1.31 | 34.60 |
| Wheat flour 75% extraction | 32.9 | 0.28 | 9.21 | 10.9 | 0.05 | 0.55 | 9.76 |
| Grits | 5.5 | 0.27 | 1.48 | 1.8 | 0.05 | 0.09 | 1.57 |
| Total | 60.3 | 0.73 | 43.98 | 20.0 | 0.10 | 1.95 | 45.93 |

## 5.9.5. Potatoes

The figures in Table 5.5.1 were used, i.e. 0.065 Bq $^{90}Sr$ $kg^{-1}$ and 0.063 Bq $^{137}Cs$ $kg^{-1}$.

5.9.6. Vegetables

Table 5.6.3 shows the calculation of $^{90}Sr$ and $^{137}Cs$ in Danish vegetables consumed in 1982. The mean contents were 0.32 Bq $^{90}Sr$ $kg^{-1}$ and 0.053 Bq $^{137}Cs$ $kg^{-1}$.

5.9.7. Fruit

The levels in imported fruit in 1982 are assumed to be equal to the mean levels found in oranges and bananas collected in Copenhagen in 1982, i.e. 0.132 Bq $^{90}Sr$ $kg^{-1}$ and 0.024 Bq $^{137}Cs$ $kg^{-1}$. The mean levels in Danish fruit (apples) in 1982 were 0.023 Bq $^{90}Sr$ $kg^{-1}$ and 0.044 Bq $^{137}Cs$ $kg^{-1}$ (cf. 5.6). The daily mean consumption of fruit consisted of 100 g of Danish and 40 g of foreign origin. Hence the mean contents in fruit were 0.054 Bq $^{90}Sr$ $kg^{-1}$ and 0.038 Bq $^{137}Cs$ $kg^{-1}$.

5.9.8. Meat

The annual mean values of $^{90}Sr$ and $^{137}Cs$ in meat were calculated from Table 5.8.1: 0.020 Bq $^{90}Sr$ $kg^{-1}$ and 0.38 Bq $^{137}Cs$ $kg^{-1}$. (In a Danish diet meat comprises 2/3 pork and 1/3 beef).

5.9.9. Fish

The $^{90}Sr$ and $^{137}Cs$ contents in fish are estimated from 5.8.2 at 0.022 Bq $^{90}Sr$ $kg^{-1}$ and 4.2 Bq $^{137}Cs$ $kg^{-1}$.

5.9.10. Eggs

The contents of activity in eggs were estimated from 5.8.3. The levels were 0.030 Bq $^{90}Sr$ $kg^{-1}$ and 0.033 Bq $^{137}Cs$ $kg^{-1}$.

5.9.11. Coffee and tea

One third of the total consumption consists of tea and two thirds of coffee. We use the mean contents from 1982: 0.87 Bq $^{90}Sr$ $kg^{-1}$ and 2.53 Bq $^{137}Cs$ $kg^{-1}$.[1)]

## 5.9.12. Drinking water

The $^{90}Sr$ level (population-weighted mean) found in drinking water collected in April 1982 (4.3.3) was used as the mean level for drinking water, i.e. 0.0005 Bq $^{90}Sr$ $kg^{-1}$. The $^{137}Cs$ content in drinking water is assumed to be negligible.

## 5.9.13. Discussion

Tables 5.9.3 and 5.9.4 show the estimates of $^{90}Sr$ and $^{137}Cs$ in the Danish diet in 1982. The figures should be compared with the levels calculated from the total-diet samples (cf. 5.7). The $^{90}Sr$ estimates obtained by the two methods (cf. also fig. 5.7.1) were 151 Bq (kg Ca)$^{-1}$ and 152 Bq (kg Ca)$^{-1}$, respectively, and the $^{137}Cs$ estimates were 0.42 Bq $^{137}Cs$ (day)$^{-1}$ and 0.40 Bq $^{137}Cs$ (day)$^{-1}$.

Table 5.9.3. Estimate of the mean content of $^{90}Sr$ in the human diet in 1982

| Type of food | Annual quantity in kg | Bq $^{90}Sr$ per kg | Total Bq $^{90}Sr$ | Percentage of total Bq $^{90}Sr$ in food |
|---|---|---|---|---|
| Milk and cream | 164.0 | 0.122 | 20.01 | 21.4 |
| Cheese | 9.1 | 0.87 | 7.92 | 8.5 |
| Grain products | 80.3 | 0.47 | 37.48 | 40.0 |
| Potatoes | 73.0 | 0.065 | 4.75 | 5.1 |
| Vegetables | 43.8 | 0.32 | 14.02 | 15.0 |
| Fruit | 51.1 | 0.054 | 2.76 | 2.9 |
| Meat | 54.7 | 0.020 | 1.09 | 1.2 |
| Eggs | 10.9 | 0.030 | 0.33 | 0.3 |
| Fish | 10.9 | 0.022 | 0.24 | 0.2 |
| Coffee and tea | 5.5 | 0.87 | 4.78 | 5.1 |
| Drinking water | 548 | 0.0005 | 0.27 | 0.3 |
| Total | | | 93.65 | |

The mean Ca intake was estimated at 0.62 kg $y^{-1}$ (approx. 0.2-0.25 kg creta praeparata). Hence the $^{90}Sr/Ca$ ratio in total diet was 151 Bq $^{90}Sr$ (kg Ca)$^{-1}$ (4.1 S.U.) in 1982.

Table 5.9.4. Estimate of the mean content of $^{137}Cs$ in the human diet in 1982

| Type of food | Annual quantity in kg | Bq $^{137}Cs$ per kg | Total Bq $^{137}Cs$ | Percentage of total Bq $^{137}Cs$ in food |
|---|---|---|---|---|
| Milk and cream | 164.0 | 0.105 | 17.22 | 11.2 (15.3) |
| Cheese | 9.1 | 0.076 | 0.69 | 0.5 ( 0.6) |
| Grain products | 80.3 | 0.57 | 45.93 | 29.9 (40.9) |
| Potatoes | 73.0 | 0.063 | 4.60 | 3.0 ( 4.1) |
| Vegetables | 43.8 | 0.053 | 2.32 | 1.5 ( 2.1) |
| Fruit | 51.1 | 0.038 | 1.94 | 1.3 ( 1.7) |
| Meat | 54.7 | 0.38 | 20.79 | 13.5 (18.5) |
| Eggs | 10.9 | 0.033 | 0.36 | 0.2 ( 0.3) |
| Fish | 10.9 | 4.2 | 45.78(4.58) | 29.8 ( 4.1) |
| Coffee and tea | 5.5 | 2.53 | 13.92 | 9.1 (12.4) |
| Drinking water | 548 | 0 | 0 | 0 ( 0 ) |
| Total | | | 153.55 (112.35) | |

In brackets are shown the values if the contribution of Sellafield $^{137}Cs$ in fish is excluded. This contribution is approx. 90% of the $^{137}Cs$ content in Danish fish. Sellafield thus contributed with approximately 27% of the total $^{137}Cs$ content in Danish diet in 1982.

As the approximate intake of potassium was 1.365 kg $y^{-1}$ the $^{137}Cs/K$ ratios were 112 (82.3) Bq $^{137}Cs$ (kg K)$^{-1}$ or 3.0 (2.22) M.U. in 1982.

The ratio between observed and predicted (cf. Appendix C) diet levels was 1.03 for $^{90}Sr$ and 0.94 for $^{137}Cs$ (corrected for Sellafield $^{137}Cs$).

The relative contributions of $^{90}Sr$ from milk products (~ 30%) and from grain (40%) were similar to those in 1978-1981. The contribution from potatoes, other vegetables, and fruit was ~ 23%, i.e. nearly the same as in 1981. The relative contribution of $^{137}Cs$ in the total diet changed from 1980 to 1981 as follows: milk products (14 to 12%), grain products increased

from 17 to 30%, and meat increased (12 to 14%). Fish contributed 30% to the total $^{137}Cs$ intake in 1982, and is thus together with grain products the most important source of $^{137}Cs$. This is, however, due to the $^{137}Cs$ contribution from Sellafield. If this was excluded, milk products would contribute with 16%, grain: 41%, meat: 19% and fish: 4%.

## 5.10. Grass samples

### 5.10.1. Grass collected around Risø

Table 5.10.1.1 shows the $^{90}Sr$ content in grass ash from Zealand in 1982. The mean $^{90}Sr$ activity was 34 Bq $^{90}Sr$ (kg ash)$^{-1}$, or 720 Bq $^{90}Sr$ (kg Ca)$^{-1}$, i.e. the 1982 level was 60% of the 1981 level. Figure 5.10 shows the $^{90}Sr$ concentration in grass since 1957. The ratio between observed and predicted (cf. Appendix C.1) $^{90}Sr$ level in grass in 1982 was 1.27.

Table 5.10.1.1. Strontium-90 in grass from Zealand, 1982

| | Bq $^{90}Sr$ (kg ash)$^{-1}$ | Bq $^{90}Sr$ (kg Ca)$^{-1}$ |
|---|---|---|
| Jan-March | 30 | 880 |
| April-June | 28 | 640 |
| July-Sept | 46 | 810 |
| Oct-Dec | 30 | 530 |
| Mean | 34 | 720 |
| Mean | 0.91 pCi g$^{-1}$ | 19.3 S.U. |

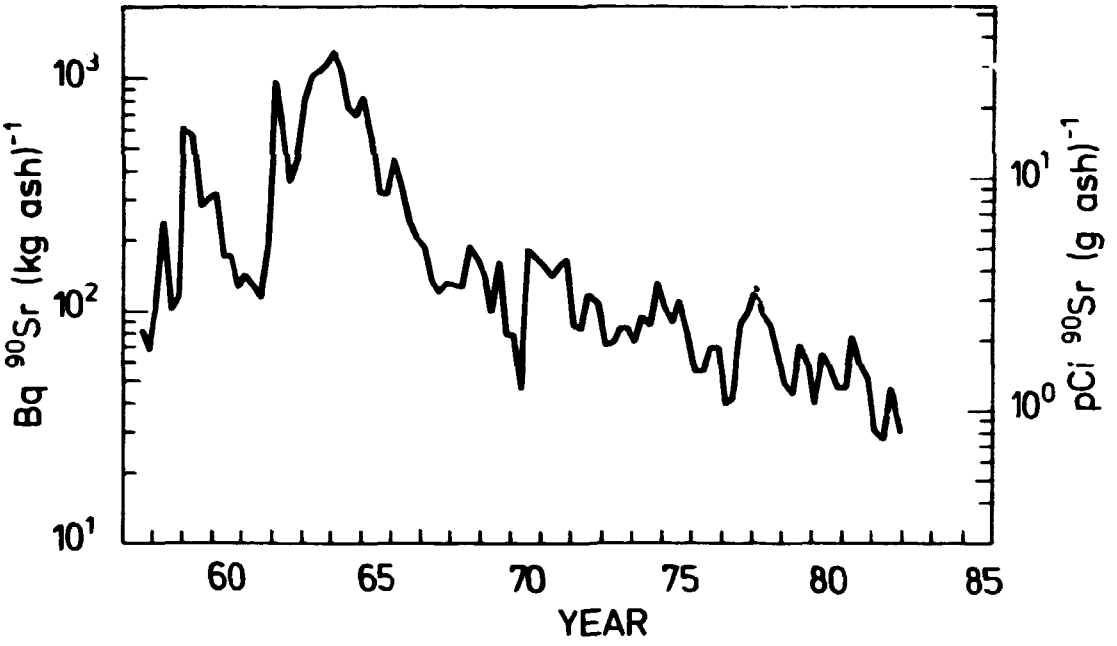


Fig. 5.10. Quarterly $^{90}$Sr levels in grass, 1957-1982.

Table 5.10.1.2. Cesium-137 and Kalium-40 in grass from Risø, 1982

| Month | n | Bq $^{137}$Cs kg$^{-1}$ fresh | Bq $^{137}$Cs m$^{-2}$ | g $^{40}$K kg$^{-1}$ fresh |
|---|---|---|---|---|
| Jan* | | | | |
| Feb | 3 | 1.07±0.32 | 0.77±0.04 | 2.7±0.5 |
| March | 5 | 1.38±0.19 | 0.77±0.09 | 2.6±0.2 |
| April | 3 | 1.46±0.22 | 0.61±0.22 | 4.2±1.1 |
| May | 4 | B.D.L. | B.D.L. | 5.7±0.5 |
| June | 5 | " | " | 5.1±0.6 |
| July | 4 | " | " | 5.6±0.3 |
| Aug | 5 | " | " | 5.5±0.6 |
| Sept | 4 | " | " | 4.6±0.5 |
| Oct | 4 | " | " | 4.2±0.6 |
| Nov | 4 | " | " | 3.7±0.6 |
| Dec | 3 | " | " | 2.8±0.3 |

The error term is 1 S.E. of the mean.

*Snow

## 5.11. Sea plants

### 5.11.1. Sea plants collected in Roskilde Fjord

Figure 5.11.1 shows the Bq $^{90}Sr$ (kg Ca)$^{-1}$ levels in sea plants since 1959 and Table 5.11.1.A the results for 1982. The mean level in Fucus vesiculosus was 400 Bq $^{90}Sr$ (kg Ca)$^{-1}$ (9.2 Bq kg$^{-1}$ dry weight), and in Zostera marina 90 Bq $^{90}Sr$ (kg Ca)$^{-1}$ (2.1 Bq kg$^{-1}$ dry weight). The mean ratio between observed and predicted $^{90}Sr$ levels in sea plants was 0.96.

Zostera marina contained 1.8 Bq $^{137}Cs$ kg$^{-1}$ dry weight and Fucus vesiculosus 8.7. The concentration ratio between sea plants and sea water is thus approximately 40% higher for $^{90}Sr$ than for $^{137}Cs$.

For comparison the results from 1981 are shown again, because some of the results were given as fresh weight instead of dry weight concentrations.

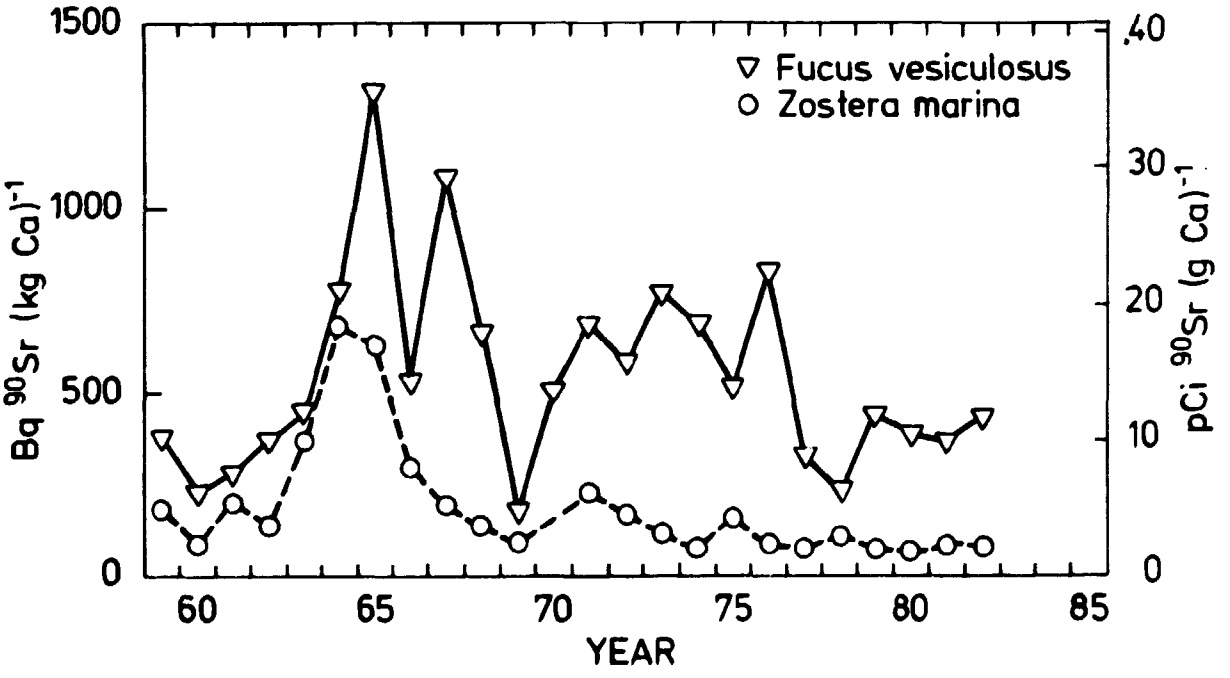


Fig. 5.11.1. Strontium-90 in sea plants from Roskilde fjord, 1959-1982.

Table 5.11.1.A. Strontium-90 and Cesium-137 in sea plants from Roskilde Fjord in 1982

| Location | Species | Date | fresh/dry | Bq $^{90}Sr$ (kg Ca)$^{-1}$ | Bq $^{90}Sr$ kg$^{-1}$ dry weight | Bq $^{137}Cs$ (kg K)$^{-1}$ | Bq $^{137}Cs$ kg$^{-1}$ dry weight |
|---|---|---|---|---|---|---|---|
| III | Zostera marina | 1/3 | | 104 | 2.8 | 183 A | 2.0 A |
| I | Zostera marina | 9/9 | 7.84 | 76 | 1.31 | 42 | 1.63 |
| I | Fucus vesiculosus | 1/3 | | 370 | 10.3 | 280 | 8.0 |
| I | Fucus vesiculosus | 1/11 | 3.88 | 430 | 8.2 | 310 | 8.2 |
| I | - " - | 22/7 | 5.42 | - | - | 300 | 9.9 |

Table 5.11.1.B. Strontium-90 and Cesium-137 in sea plants from Roskilde Fjord in 1981

| Location | Species | Date | Bq $^{90}Sr$ (kg Ca)$^{-1}$ | Bq $^{90}Sr$ kg$^{-1}$ dry weight | Bq $^{137}Cs$ (kg K)$^{-1}$ | Bq $^{137}Cs$ kg$^{-1}$ dry weight |
|---|---|---|---|---|---|---|
| I | Zostera marina | 10/6 | 81 | 1.36 | 23 A | 0.9 A |
| IX | Zostera marina | 3/6 | 76 | 2.1 | 38 | 1.96 |
| I | Fucus vesiculosus | 29/4 | 370 | 5.8 | 320 | 10.9 |
| I | Fucus vesiculosus | 9/6 | | | 340 | 11.8 |

Due to errors in the 1981 data, the table from 1981 is reprinted.

## 5.11.2 Sea plants collected in Danish waters in 1982

In 1982 we collected 36 samples of algae and 1 sample of Zostera marina from the Danish Straits, the Baltic, and North Seas. The samples have been analysed for γ-emitters, especially radiocesium and $^{60}Co$, and in some cases for Pu and Am (cf. Tables 5.11.2.1 and 5.11.2.2).

The mean $^{137}Cs$ content in brown algae collected in the inner Danish waters was 10.25±1.85 Bq kg$^{-1}$ dry weight (1 S.D., N = 33) or 2.31±0.51 Bq kg$^{-1}$ fresh weight. The dry weight figure was 85% of that in 1981 while the fresh weight value was 105% of the corresponding level in 1981.

The 3 samples from the North Sea contained 5.63±1.10 Bq $^{137}Cs$ kg$^{-1}$ dry weight or 1.29±0.30 Bq $^{137}Cs$ kg$^{-1}$ fresh weight. This is significantly lower than the concentrations in the inner Danish waters. As the water concentrations of $^{137}Cs$ are higher in the

Table 5.11.2.1. Gamma-emitting radionuclides in brown algae collected in inner Danish waters in 1982 (Unit: Bq $kg^{-1}$ dry)

| Species | Location | Date | dry weight / fresh weight | Salinity Cl. o/oo | $^{54}Mn$ | $^{60}Co$ | $^{65}Zn$ | $^{95}Zr$ | $^{95}Nb$ | $^{106}Ru$ | $^{110m}Ag$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Laminaria saccharina | 57°43'N 10°34'E Skagen | 11/7 | 0.197 | | | | | | | | |
| Fucus vesiculosus | 57°39'N 11°41'E at Göteborg | 10/7 | 0.228 | | 0.73 | 1.68 | 2.1 | | | | |
| Fucus vesiculosus | 57°27'N 10°33'E Fredrikshavn | 28/9 | 0.246 | 25.2 | | 0.83 | | | | | |
| Fucus vesiculosus | 57°20'N 10°32'E Sæby | 28/9 | 0.236 | 25.2 | 0.74 | 0.60 | | | | | |
| Fucus serratus | 57°19'N 11°08'E Østerby, Læsø | 24/10 | 0.261 | | 0.63 | 1.37 | | | | 3.5 | |
| Fucus serratus | 57°18'N 10°56'E Vesterøby, Læsø | 24/10 | 0.244 | | 0.45 | 1.09 | | | | | |
| Fucus vesiculosus | 57°07'N 12°11'E Getterön, Stara näs | 24/10 | 0.254 | | | 3.0 | | | | | |
| Fucus vesiculosus | 57°04'N 10°22'E Nou | 27/9 | 0.233 | 22.7 | 0.74 | 0.59 | | | | | |
| Fucus vesiculosus | 57°02'N 12°19'E Galtebäck hamn | 24/10 | 0.260 | 19 | 0.61 | 2.4 | | | | | |
| Fucus vesiculosus | 56°54'N 10°16'E Dokkedal (West) | 27/9 | 0.224 | | 0.43 | 0.37 | | | | | |
| Fucus vesiculosus | 56°54'N 10°16'E Dokkedal (East) | 27/9 | 0.229 | | | 0.91 | | | | | |
| Fucus vesiculosus | 56°50'N 12°33'E Bobergs udde | 24/10 | 0.220 | 19 | | 2.2 | | | | | |
| Fucus vesiculosus | 56°45'N 10°18'E Als, Himmerland (West) | 27/9 | 0.223 | 23.4 | 0.64 | 0.75 | | | | | |
| Fucus vesiculosus | 56°45'N 10°18'E Als, Himmerland (East) | 27/9 | 0.223 | | | 0.47 | | | | | |
| Fucus vesiculosus | 56°43'N 11°31'E Anholt | 10/5 | 0.165 | | | 1.43 | | | | | |
| Fucus vesiculosu | 56°36'N 10°19'E Udbyhøj | 27/9 | 0.192 | 19.0 | 0.89 | 0.59 | | | | | |
| Fucus vesiculosus | 56°31'N 10°27'E Lystrup | 27/9 | 0.224 | 24.5 | 0.48 | 0.69 | | | | | |
| Fucus serratus | 56°31'N 10°27'E Lystrup | 27/9 | 0.308 | | 0.80 | 0.74 | | | | | |
| Fucus vesiculosus | 56°27'N 10°58'E Fornæs Fyr | 27/9 | 0.240 | 24.5 | 0.43 | 0.65 | | | | | |
| Fucus vesiculosus | 56°26'N 12°38'E Torekov | 24/10 | 0.249 | 18 | | 3.4 | | | | | |
| Fucus vesiculosus | 56°23'N 10°56'E Grenå | 27/9 | 0.251 | 24.0 | | 0.97 | | | | | |
| Fucus vesiculosus | 56°17'N 12°30'E Mölle/Kullen | 24/10 | 0.250 | 18 | | 4.6 | | | | | |
| Ascophyllum nodosum | 56°17'N 12°30'E Mölle/Kullen | 24/10 | 0.242 | 18 | | 2.3 | | | | | |
| Fucus vesiculosus | 56°12'N 11°43'E Hesselø | 28/10 | 0.223 | | | 1.69 | | | | | |
| Fucus serratus | 56°12'N 11°43'E Hesselø | 28/10 | 0.246 | | | 2.7 | | | | | |
| Fucus vesiculosus | 56°04'N 12°41'E Helsingborg | 16/9 | 0.243 | | | 9.4 | | | | | |
| Fucus serratus | 56°03'N 12°36'E Helsingør | 26/5 | 0.246 | | 0.52 | 3.8 | 1.1 | | 1.5 | | |
| Fucus serratus | 55°45'N 12°35'E Skovshoved | 21/4 | 0.208 | | 0.89 | 4.9 | 1.3 | 0.9 | 0.87 | | 1.0 |
| Fucus serratus | 55°45'N 12°35'E Skovshoved | 24/6 | 0.221 | | 0.98 | 5.2 | | | | | |
| Fucus vesiculosus | 55°31'N 09°46'E Fredericia | 12/10 | 0.275 | 17.3 | | <0.26 | | | | | |
| Fucus vesiculosus | 55°09'N 15°06'E Svenskehavn | 18/11 | 0.190 | | 0.93 | <0.27 | | | | | |
| Fucus serratus | 54°57'N 12°28'E Klintholm | 14/12 | 0.170 | | 1.11 | 0.85 | | | | | |
| Fucus serratus | 54°39'N 11°21'E Rødby | 14/12 | 0.198 | | 1.03 | 0.48 | | | | | |
| Zostera marina | 54°33'N 11°58'E Gedser | 14/12 | 0.122 | | | <0.27 | | | | | |
| Fucus vesiculosus | 55°27'N 8°28'E Esbjerg South | 12/10 | 0.233 | 26 | 0.51 | 0.59 | | | | | |
| Fucus vesiculosus | 55°29'N 8°25'E Esbjerg Northwest | 12/10 | 0.206 | 26 | 0.51A | 0.34A | | | | | |
| Fucus vesiculosus | 55°05'N 8°14'E Havneby, Rømø | 12/10 | 0.247 | 26 | 0.3 B | 0.46A | | | | | |

Table 5.11.2.2. Radionuclides in brown algae collected in inner Danish waters in 1982 (Unit: Bq $kg^{-1}$ dry)

| Species | Location | Date | dry weight / fresh weight | Salinity Cl. o/oo | $^{125}Sb$ | $^{131}I$ | $^{134}Cs$ | $^{137}Cs$ | $^{144}Ce$ | $^{239,240}Pu$ | $^{241}Am$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Laminaria saccharina | 57°43'N 10°34'E Skagen | 11/7 | 0.197 | | | | 0.39 | 13.4 | | | |
| Fucus vesiculosus | 57°39'N 11°41'E at Göteborg | 10/7 | 0.228 | | | | 0.36 | 15.6 | 2.4 | | |
| Fucus vesiculosus | 57°27'N 10°33'E Frederikshavn | 28/9 | 0.246 | 25.2 | | | | 9.0 | | 0.050 | 0.005 |
| Fucus vesiculosus | 57°20'N 10°32'E Saby | 28/9 | 0.236 | 25.2 | 0.69 | | 0.27 | 10.6 | | | |
| Fucus serratus | 57°19'N 11°08'E Østerby, Læsø | 24/10 | 0.261 | | | | | 7.8 | | | |
| Fucus serratus | 57°18'N 10°56'E Versterøby, Læsø | 24/10 | 0.244 | | | | | 9.3 | | | |
| Fucus vesiculosus | 57°07'N 12°11'E Getterön, Stara näs | 24/10 | 0.254 | | | | | 10.8 | | 0.071 | 0.0067 |
| Fucus vesiculosus | 57°04'N 10°22'E Hou | 27/9 | 0.233 | 22.7 | | | | 10.1 | | | |
| Fucus vesiculosus | 57°02'N 12°19'E Galtebäck hamn | 24/10 | 0.260 | 19 | | | | 10.0 | | | |
| Fucus vesiculosus | 56°54'N 10°16'E Dokkedal (West) | 27/9 | 0.224 | | | | 0.29 | 11.3 | | | |
| Fucus vesiculosus | 56°54'N 10°16'E Dokkedal (East) | 27/9 | 0.229 | | | | | 12.2 | | | |
| Fucus vesiculosus | 56°50'N 12°33'E Boberqs udde | 24/10 | 0.220 | 19 | | | | 10.1 | | | |
| Fucus vesiculosus | 56°45'N 10°18'E Als, Himmerland (West) | 27/9 | 0.223 | 23.4 | | | 0.41 | 12.6 | | | |
| Fucus vesiculosus | 56°45'N 10°18'E Als, Himmerland (East) | 27/9 | 0.223 | | | | | 9.4 | | | |
| Fucus vesiculosus | 56°43'N 11°31'E Anholt | 10/5 | 0.165 | | | | | 9.. | | | |
| Fucus vesiculosus | 56°36'N 10°19'E Udbyhøj | 27/9 | 0.192 | 19.0 | 1.06 | | | 12.6 | | | |
| Fucus vesiculosus | 56°31'N 10°27'E Lystrup | 27/9 | 0.224 | 24.5 | | | 0.33 | 10.1 | | | |
| Fucus serratus | 56°31'N 10°27'E Lystrup | 27/9 | 0.308 | | | | | 10.5 | | | |
| Fucus vesiculosus | 56°27'N 10°58'E Fornæs Fyr | 27/9 | 0.240 | 24.5 | | | 0.24 | 11.5 | | 0.060 | 0.0154 |
| Fucus vesiculosus | 56°26'N 12°30'E Torekov | 24/10 | 0.269 | 18 | | | | 8.4 | | | |
| Fucus vesiculosus | 56°23'N 10°56'E Grenå | 27/9 | 0.251 | 24.0 | | | | 11.6 | | | |
| Fucus vesiculosus | 56°17'N 12°30'E Mölle/Kullen | 24/10 | 0.250 | 18 | | | | 9.5 | | 0.082 | B.D.L. |
| Ascophyllum nodosum | 56°17'N 12°30'E Mölle/Kullen | 24/10 | 0.242 | 18 | | | | 6.9 | | | |
| Fucus vesiculosus | 56°12'N 11°43'E Hesselø | 28/10 | 0.223 | | | | | 10.7 | | 0.045 | 0.007B |
| Fucus serratus | 56°12'N 11°43'E Hesselø | 28/10 | 0.246 | | | | | 8.6 | | | |
| Fucus vesiculosus | 56°04'N 12°41'E Helsingborg | 16/9 | 0.243 | | | | | 8.5 | | | |
| Fucus serratus | 56°03'N 12°36'E Helsingør | 26/5 | 0.146 | | | | | 8.9 | 3.3 | | |
| Fucus serratus | 55°45'N 12°35'E Skovshoved | 21/4 | 0.208 | | | 16.8 | 0.17 | 11.1 | 2.2 | | |
| Fucus serratus | 55°45'N 12°35'E Skovshoved | 24/8 | 0.221 | | | | | 11.7 | 3.0 | | |
| Fucus vesiculosus | 55°31'N 09°46'E Fredericia | 12/10 | 0.215 | 17.3 | | | | 10.0 | | 0.045 | 0.009 |
| Fucus vesiculosus | 55°09'N 15°06'E Svenskehavn | 10/11 | 0.190 | | | | | 6.7 | | 0.048 | B.D.L. |
| Fucus serratus | 54°57'N 12°28'E Klinthole | 14/12 | 0.170 | | | | | 8.6 | | 0.176 | 0.009B |
| Fucus serratus | 54°39'N 11°21'E Rødby | 14/12 | 0.198 | | | | | 10.7 | | | |
| Zostera marina | 54°33'N 11°58'E Gedser | 14/12 | 0.122 | | | | | 1.3 | | | |
| Fucus vesiculosus | 55°27'N 8°28'E Esbjerg South | 12/10 | 0.233 | 28 | 1.53 | | | 8.9 | | | |
| Fucus vesiculosus | 55°29'N 8°25'E Esbjerg Northwest | 12/10 | 0.208 | 28 | 0.91A | | | 6.9 | | 0.018 | 0.0044A |
| Fucus vesiculosus | 55°05'N 8°16'E Havneby, Rømø | 12/10 | 0.267 | 28 | 0.74A | | 0.17B | 5.1 | | 0.029 | 0.009 |

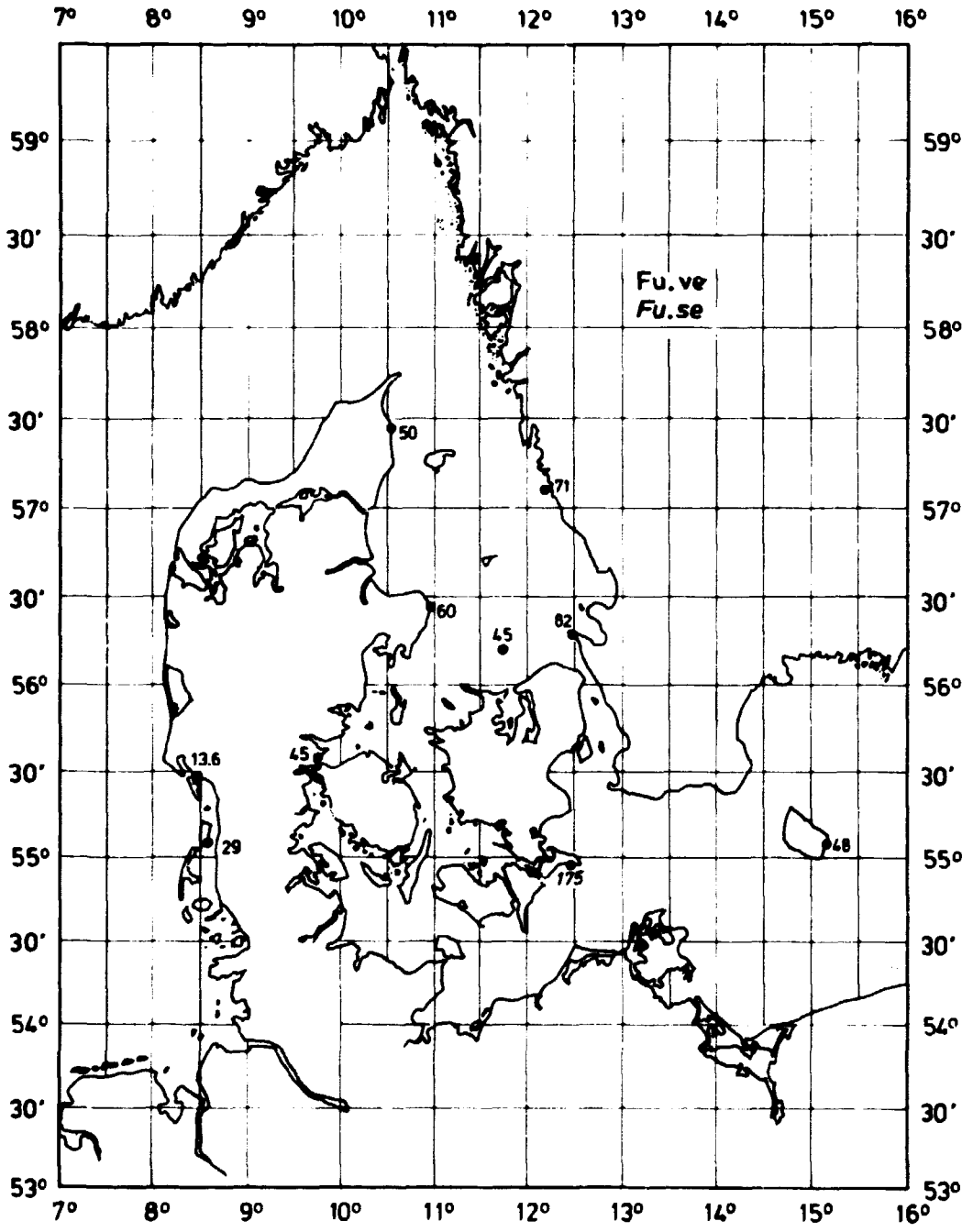


Fig. 5.11.2. Plutonium-239,240 in sea plants Fu.ve.: Fucus vesiculosus and Fu.se.: Fucus serratus in 1982. (Unit: mBq $kg^{-1}$ dry weight).

North Sea than in the Danish Straits, the concentration factor between algae and water is lower in the former than in the latter. This aggrees with observations made in earlier years.

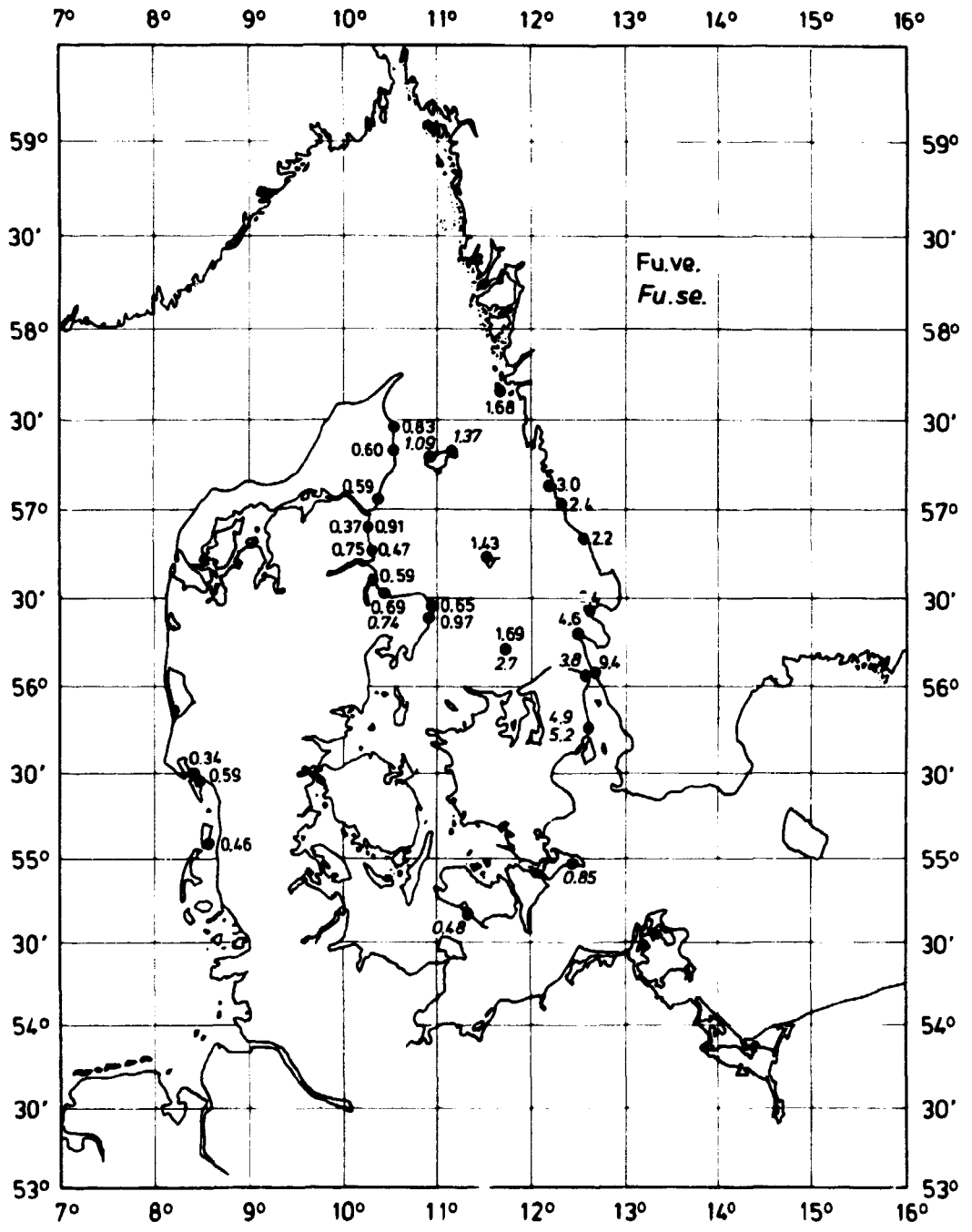


Fig. 5.11.3. Cobalt-60 in sea plants Fu.ve.: Fucus vesiculosus and Fu.se.: Fucus serratus in 1982. (Unit: Bq $kg^{-1}$ dry weight).

Cobalt-60 was measurable in nearly all samples. The data suggest that Barsebäck and Ringhals are the important sources in inner Danish waters. The samples from the North Sea are probably contaminated with $^{60}Co$ from sources in the UK and France.

The mean concentration of $^{239,240}Pu$ in samples from the Danish Straits was 0.07±0.04 Bq $kg^{-1}$ dry weight (N = 8) and the $^{241}Am/^{239,240}Am$ ratio was 0.14±0.07 (N = 6). In the North Sea samples we found 0.02±0.01 Bq $^{239,240}Pu$ $kg^{-1}$ dry weight and $^{241}Am/^{239,240}Pu$ = 0.31±0.003 (N = 2). The relatively low Pu concentrations in the North Sea samples are remarkable. We would have expected higher levels, such as those we have seen along the Norwegian westcoast (cf. Risø Report 470, p 41-44).

Manganese-54 was measurable in several samples. There was no correlation with the $^{60}Co$ concentrations (r = 0.24). This shows that $^{54}Mn$ resulted from fallout rather than from nuclear power plants. The mean concentration in the Danish Straits was 0.72± 0.22 (N = 18) Bq $^{54}Mn$ $kg^{-1}$ dry weight; in the North Sea samples, the level was lower: 0.45±0.13 (N = 3).

Dr. Duursma kindly supplied us with two samples of algae collected in the Netherlands in 1982 (Table 5.11.3). The concentrations of radionuclides in these samples were similar to those collected at Esbjerg on the SW coast of Jylland. The relatively low concentrations in these samples suggest that Sellafield has not been a major source of activity to these samples. There may be a contribution from Cap de la Hague in France, however.

Table 5.11.3. Radionuclides in brown algae collected in the Netherlands in 1982. (Unit: Bq $kg^{-1}$ dry weight)

| Location | Oosterschelde | Westerschelde |
|---|---|---|
| Species | Ascophyllum nodosum | 90% Fucus vesiculosus<br>10% Ascophyllum nodosum |
| $^{60}Co$ | 0.31 A | 1.93 |
| $^{106}Ru$ | 2.3 A | 2.5 B |
| $^{125}Sb$ | 0.70 A | 0.54 B |
| $^{134}Cs$ | 0.12 A | 0.32 B |
| $^{137}Cs$ | 2.6 | 3.5 |
| $^{226}Ra$ | 5.8 | 28 |
| $^{239,240}Pu$ | 0.014 | 0.037 |
| $^{241}Am$ | 0.01 | 0.017 |

# 6. STRONTIUM-90 AND CESIUM-137 IN MAN IN 1982

by A. Aarkrog and J. Lippert

## 6.1. Stronium-90 in human bone

The collection of human vertebrae from the institutes of forensic medicine in Copenhagen and Århus was continued in 1982. As in the total-diet survey (cf. 5.7), the country was divided into eight zones. The samples were divided into five age groups: new-born (< 1 month) (no samples in 1982), infants (1 month-4 years), children and teenagers (5-19 years), adults (≤ 29 years), and adults (> 29 years).

Tables 6.1.1-6.1.5 show the results for the five groups. The $^{90}Sr$ concentrations in human bone collected in 1982 were nearly unchanged from those observed in 1979-1981.

The observed mean concentration in adults (≥ 30 years) was 81% of that predicted (cf. Appendix C).

Table 6.1.1. Strontium-90 in bone from new-born children (< 1 month old) in 1982

No samples.

Table 6.1.2. Strontium-90 in bone from infants (≤ 4 years) in 1982

| Zone | Age in years and months | Month of death | Sex | Bq (kg Ca)$^{-1}$ |
|---|---|---|---|---|
| II | 3 m | 2 | F | 18.6 A |
| IV | 1 y 7 m | 5 | F | 22 |

Table 6.1.3. Strontium-90 in bone from children and teenagers (≤ 19 years) in 1982

| Zone | Age in years | Month of death | Sex | Bq (kg Ca)$^{-1}$ |
|---|---|---|---|---|
| II | 19 | 9 | M | 38 |
| VI | 14 | 7 | F | 42 |
| " | 19 | 7 | M | 51 |

Table 6.1.4. Strontium-90 in vertebrae from adults (≤ 29 years) in 1982

| Zone | Age in years | Month of death | Sex | Bq (kg Ca)$^{-1}$ |
|---|---|---|---|---|
| I | 23 | 8 | F | 32 |
| " | 28 | 9 | M | 28 |
| VI | 21 | 5 | M | 16.5 |
| " | 21 | 7 | M | 60 |
| " | 22 | 7 | F | 92 |
| " | 23 | 6 | M | 36 |
| " | 24 | 5 | F | 28 |
| " | 25 | 5 | M | 19.4 |
| " | 26 | 5 | F | 19.4 |
| " | 26 | 5 | F | 27 |
| " | 26 | 7 | F | 27 |
| " | 27 | 6 | M | 24 |

Table 6.1.5. Strontium-90 in vertebrae from adults (> 29 years) in 1982

| Zone | Age in years | Month of death | Sex | Bq (kg Ca)$^{-1}$ |
|---|---|---|---|---|
| I | 31 | 3 | F | 39 |
| " | 61 | 8 | M | 22 |
| II | 31 | 3 | M | 18.7 |
| " | 32 | 8 | M | 49 |
| " | 35 | 9 | F | 26 |
| " | 37 | 3 | M | 27 |
| " | 37 | 4 | M | 30 |
| " | 39 | 9 | M | 51 |
| " | 48 | 3 | M | 30 |
| " | 48 | 9 | M | 40 |
| " | 50 | 8 | M | 25 |
| " | 52 | 3 | M | 26 |
| " | 54 | 4 | F | 30 |
| " | 54 | 4 | F | 26 |
| " | 54 | 4 | M | 32 |
| " | 55 | 8 | M | 95 |
| " | 57 | 9 | M | 34 |
| " | 59 | 9 | F | 22 |
| " | 70 | 3 | F | 22 |
| " | 72 | 9 | M | 55 |
| " | 79 | 3 | F | 26 |
| III | 32 | 3 | M | 23 |
| " | 41 | 3 | M | 17.8 |
| " | 51 | 9 | F | 38 |
| IV | 43 | 1 | M | 19.5 |
| VI | 30 | 5 | M | 17.0 |
| " | 32 | 5 | F | 30 |
| " | 32 | 6 | F | 30 |
| " | 32 | 7 | F | 34 A |
| " | 34 | 5 | F | 20 |
| " | 34 | 5 | M | 29 |
| " | 42 | 5 | M | 22 |

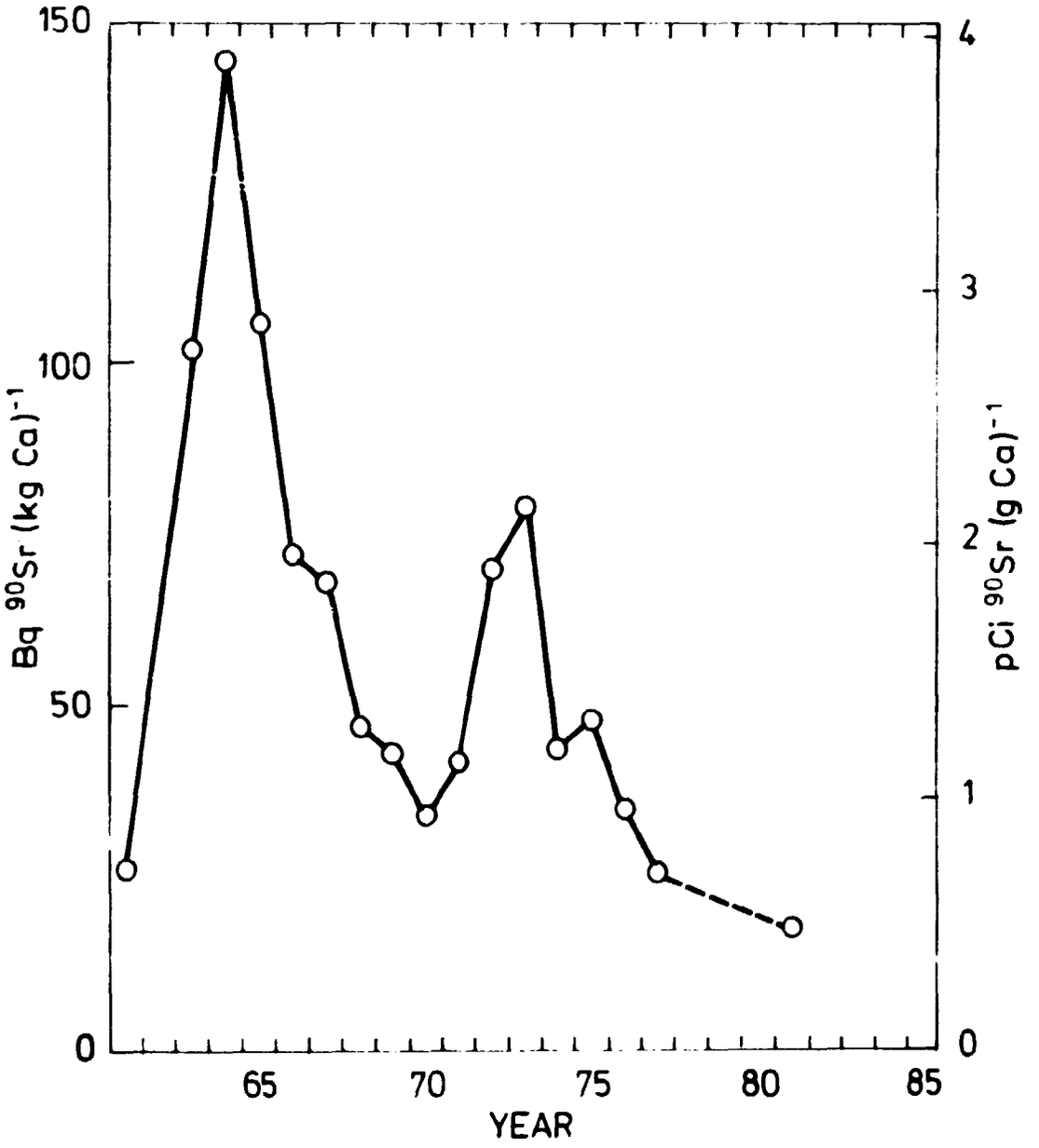


Fig. 6.1.1. Strontium-90 levels (sample number weighted mean) in bone from newborn (< 1 month) 1961-1982.

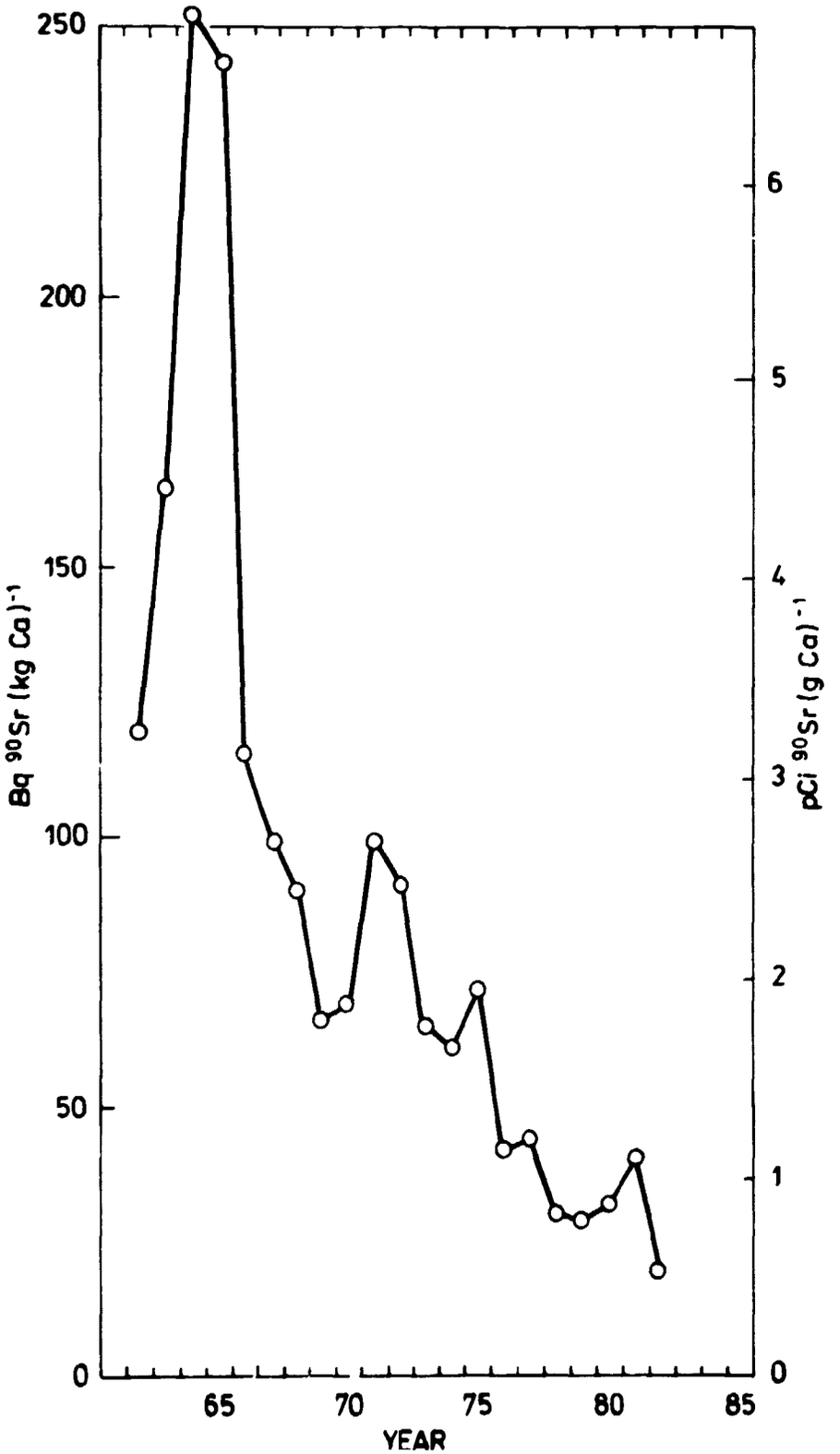


Fig. 6.1.2. Strontium-90 levels (sample number weighted mean) in bone from infants (> 1 month $\leq$ 4 years) 1962-1982.

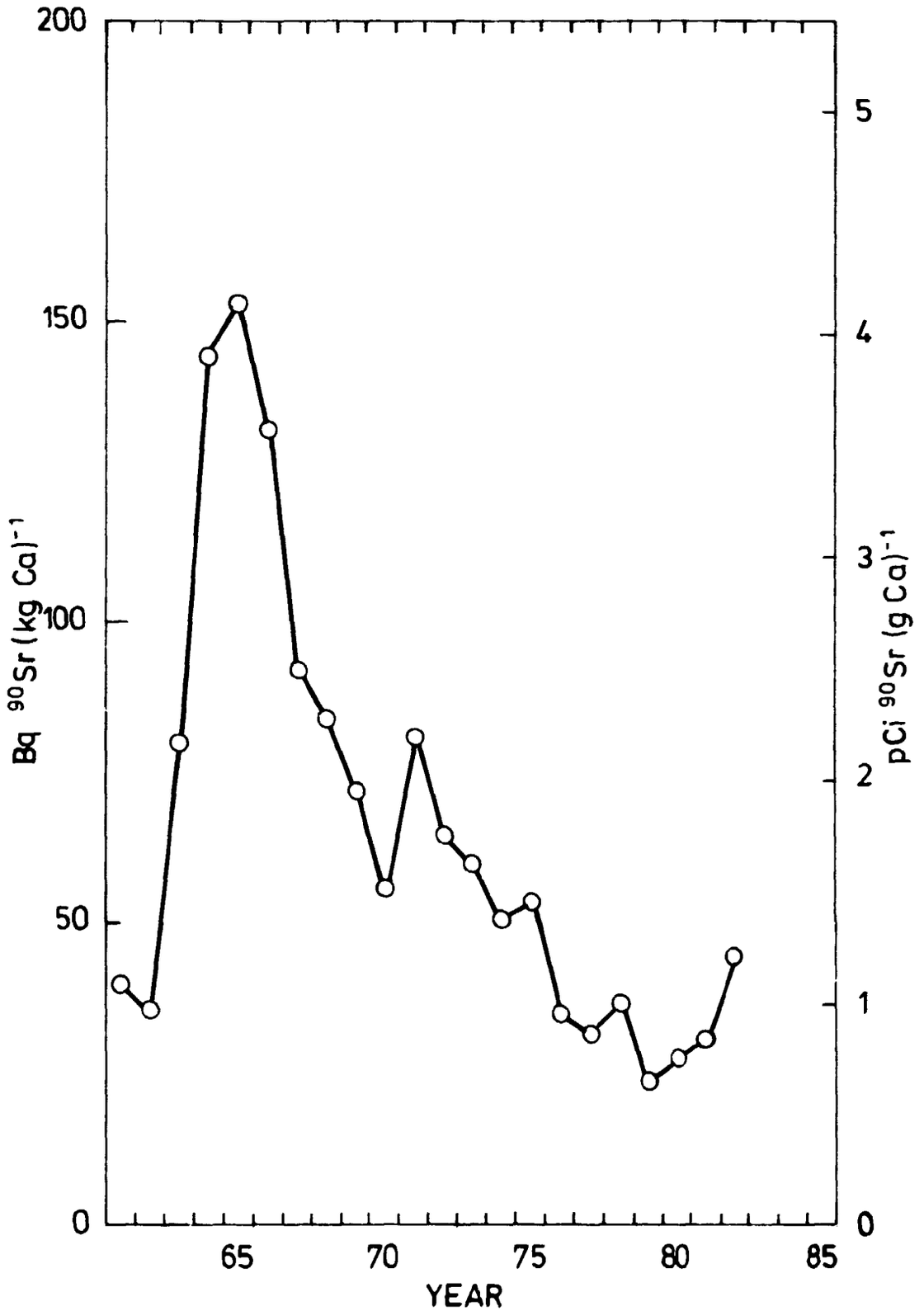


Fig. 6.1.3. Strontium-90 levels (sample number weighted mean) in bone from children (> 4 years $\leq$ 19 years) 1961-1982.

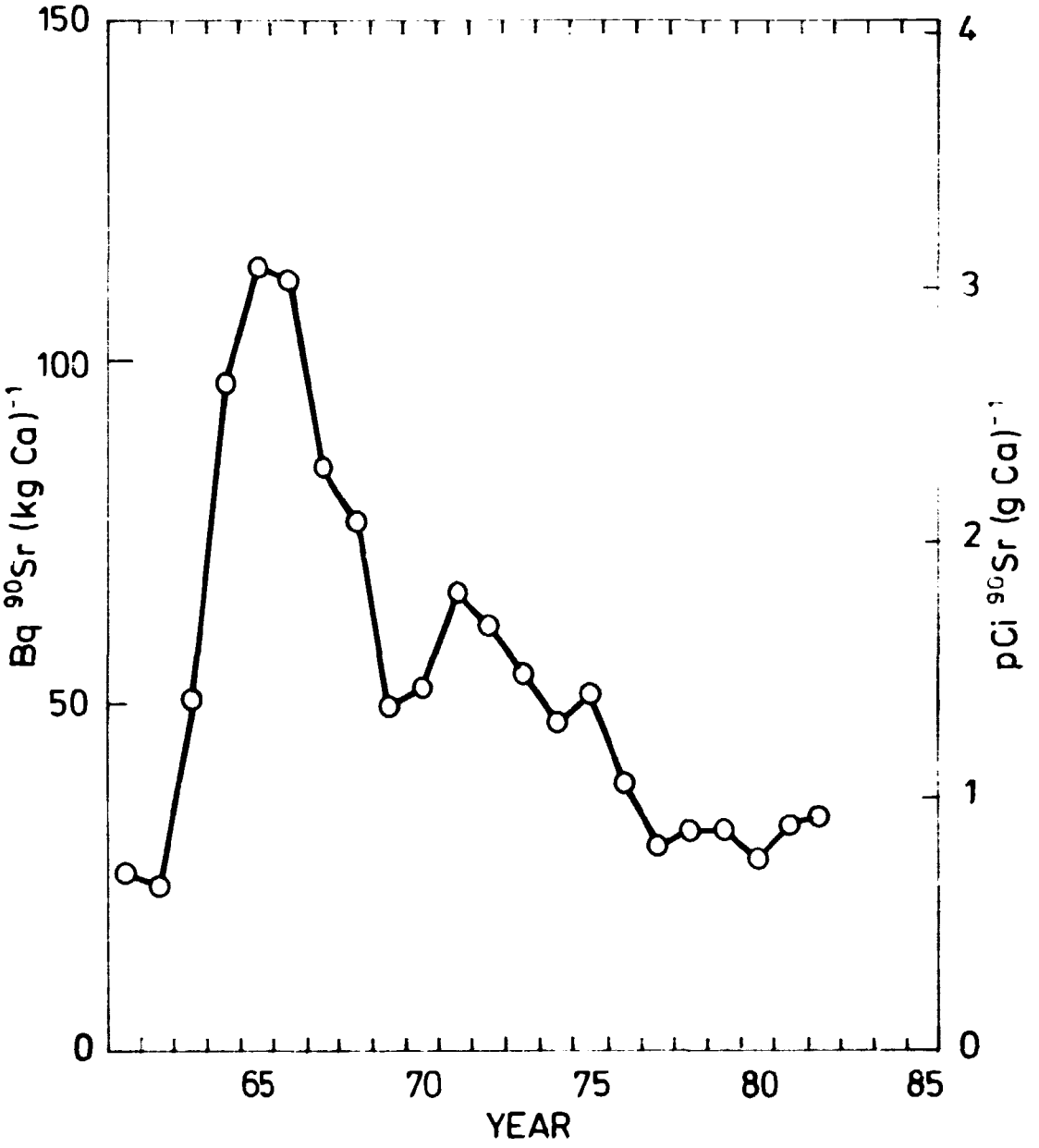


Fig. 6.1.4. Strontium-90 levels (sample number weighted mean) in bone from adults (> 19 years $\leq$ 29 years) 1961-1982.

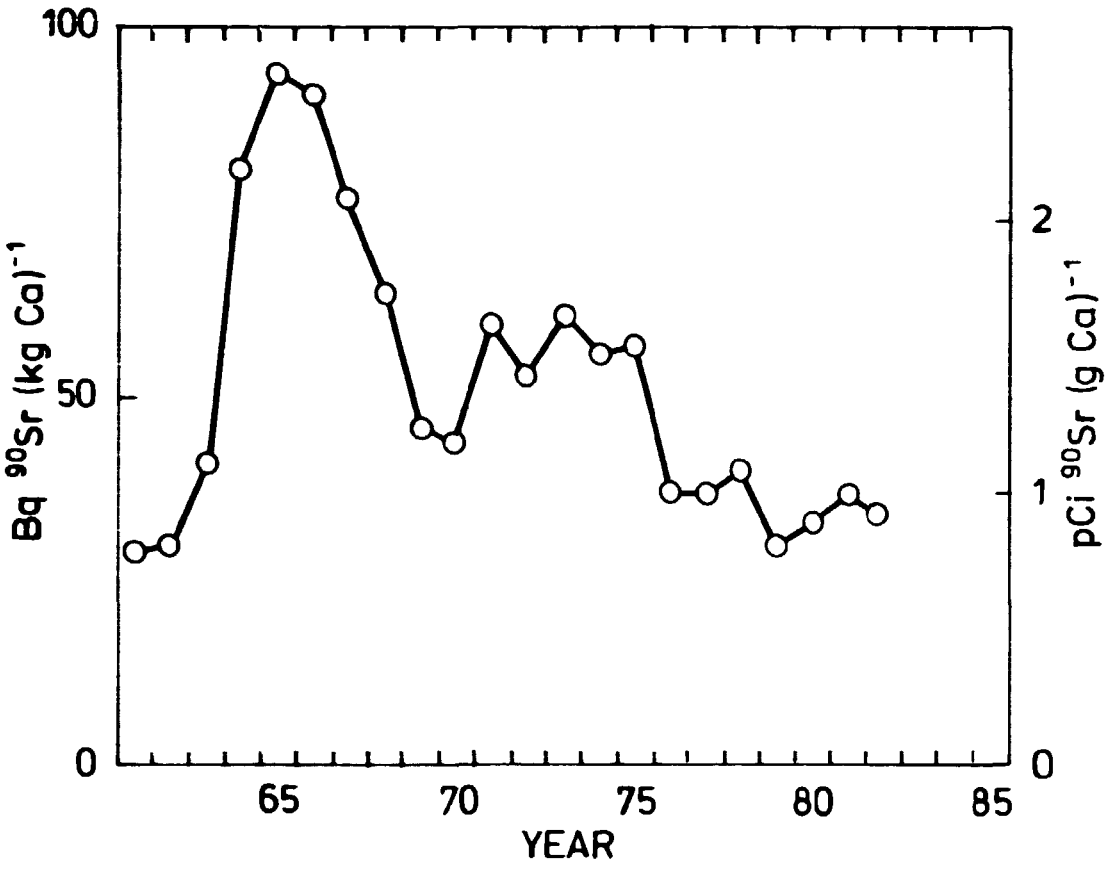


Fig. 6.1.5. Strontium-90 levels (sample number weighted mean) in bone from adults (> 29 years) 1961-1982.

Table 6.1.6. Strontium-90 in human vertebrae collected in Denmark in 1982. (Unit: Bq (kg Ca)$^{-1}$)

| Age group | Number of samples | Min. | Max. | Median | Mean |
|---|---|---|---|---|---|
| New-born (< 1 month) | 0 | | | | |
| Infants (≤ 4 years) | 2 | 18.6 | 22 | 20 | 20 |
| Children (≤ 19 years) | 3 | 38 | 51 | 42 | 44 |
| Adults (≤ 29 years) | 12 | 16.5 | 92 | 28 | 34 |
| Adults (> 29 years) | 32 | 17.0 | 95 | 28 | 34 |

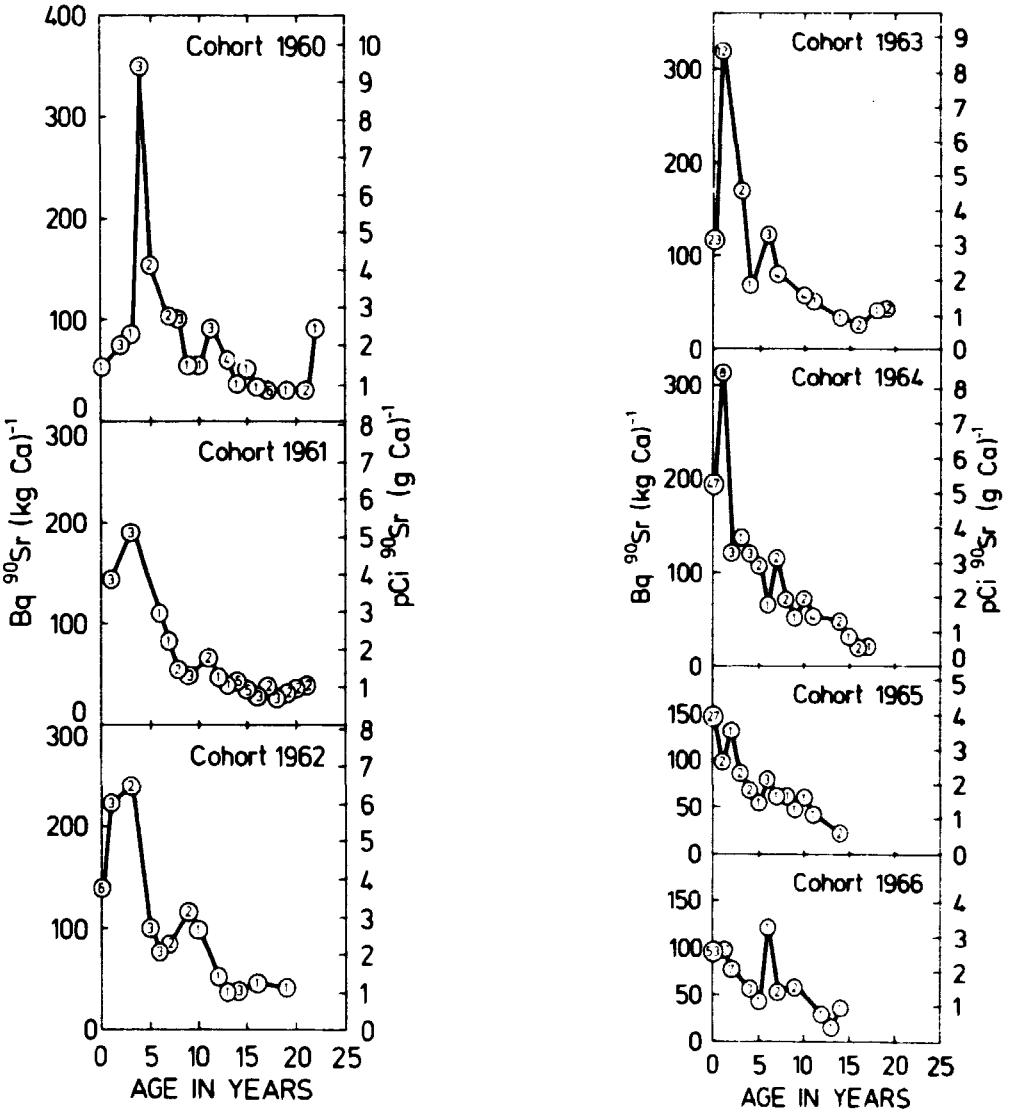


Fig. 6.1.6. Strontium-90 in human bone from Danish cohorts 1960-1966. Abscissa: age in years. Ordinate: bone level in Bq $^{90}$Sr (kg Ca)$^{-1}$.

## 6.2. Cesium-137 in the human body

Whole-body measurements were initiated at Risø in July 1963 (cf. 2.3 in Risø Report No. 85[1]). A control group from the Health Physics Department was selected and has since then been measured as far as possible three times a year.

However, due to the decreasing $^{137}$Cs content in the body the contribution from interfering radionuclides to the γ-spectra

has made the determination of $^{137}Cs$ unreliable and since 1978 we have not published whole-body measurements. From the prediction model[21] for whole body $^{137}Cs$ we have estimated the level in 1982 at 172 Bq $^{137}Cs$ (kg K)$^{-1}$ (= 4.7 pCi $^{137}Cs$ (g K)$^{-1}$) and from the diet measurements for the Islands our estimate becomes: 2.85·98 = 279 Bq $^{137}Cs$ (kg K)$^{-1}$ (= 7.5 pCi $^{137}Cs$ (g K)$^{-1}$, where 2.85 is the observed ratio between $^{137}Cs$/K in body and diet[21]. The difference between the two estimates is mainly due to the fact that the latter includes the contribution of radiocesium from Sellafield whereas the former estimate is based on fallout $^{137}Cs$ only.

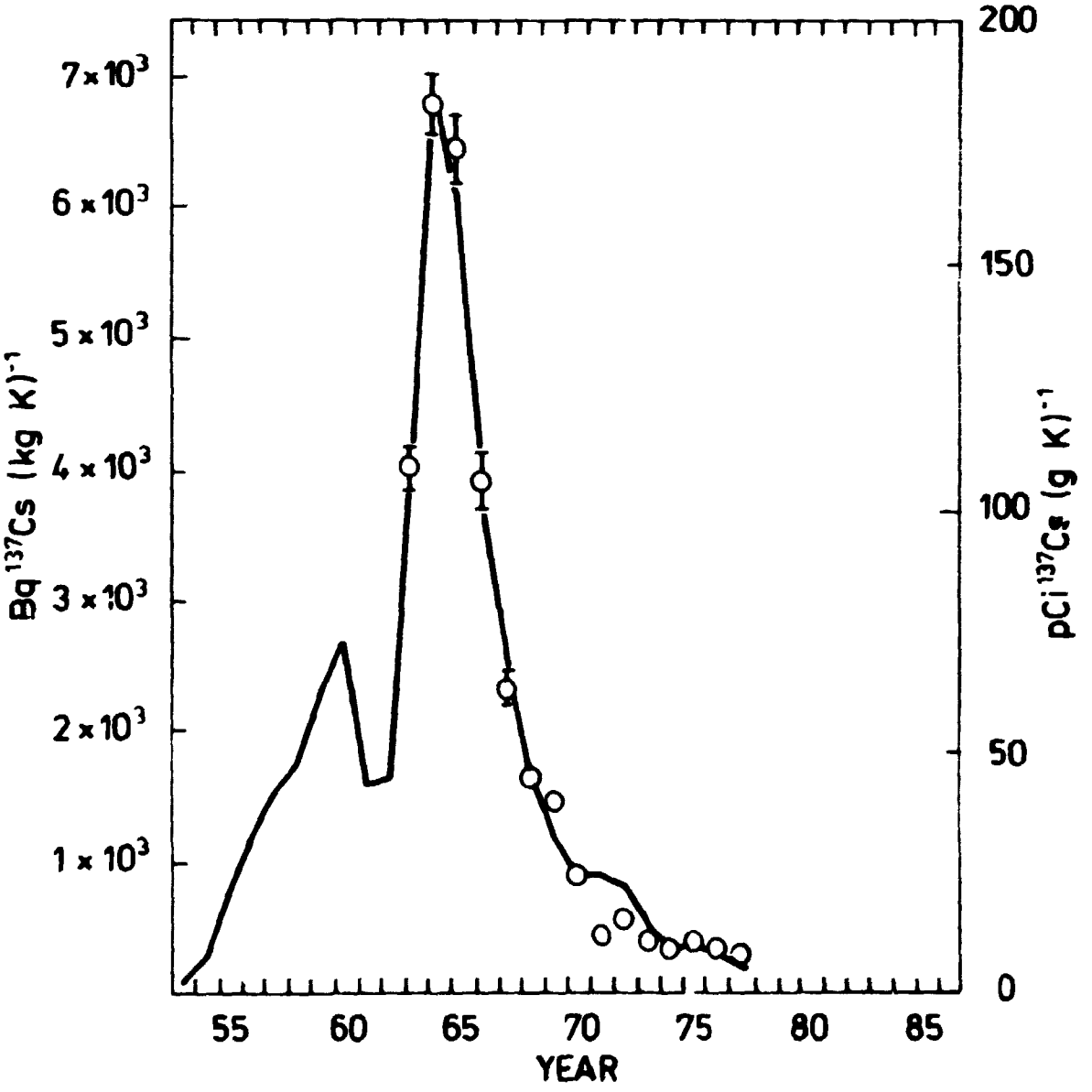


Fig. 6.2. A comparison between observed (±1 S.E.) and calculated[21] Bq $^{137}Cs$ (kg K)$^{-1}$ levels in whole-body from the Islands.

# 7. TRITIUM IN THE ENVIRONMENT

by Heinz Hansen

## 7.1. Introduction

Tritium is produced naturally in the atmosphere by the interaction of cosmic-ray protons and neutrons with nitrogen, oxygen or argon. Surface waters contain about 0.4 kBq $m^{-3}$ from this source[25]. Tritium is also produced and injected into the stratosphere as the result of thermonuclear explosions. At present, this latter source has enhanced the natural inventory by about a factor of ten[25]. Finally, tritium is produced as a by-product of the peaceful uses of atomic energy: it is released both during reactor operation and fuel reprocessing.

Before Denmark builds any nuclear power stations of her own, it is of interest to know the general tritium levels in the environment that could be affected by this new energy source. Also, an assay of the current tritium levels can be used already now to control any tritium which may be released from the Swedish nuclear power stations at Barsebäck and Ringhals, and from the reprocessing plants at Sellafield and La Hague.

## 7.2. Assay of tritium in low-level amounts

The present assays of tritium levels in water are based on a relative enrichment of $^3H_2O$ by electrolysis and subsequent liquid scintillation counting as previously described (Risø Reports Nos. 386 etc. [1]).

## 7.3 General discussion

Figure 7 shows the tritium concentrations in various water samples collected in Denmark since 1977. The tritium concentrations in ground water have been lower than the levels in other samples throughout the period. This is explained by the contribution of old water with no tritium to the ground water sources (cf. 4.3.1). Stream and lake water show concentrations mainly between those of ground water and precipitation. This indicates

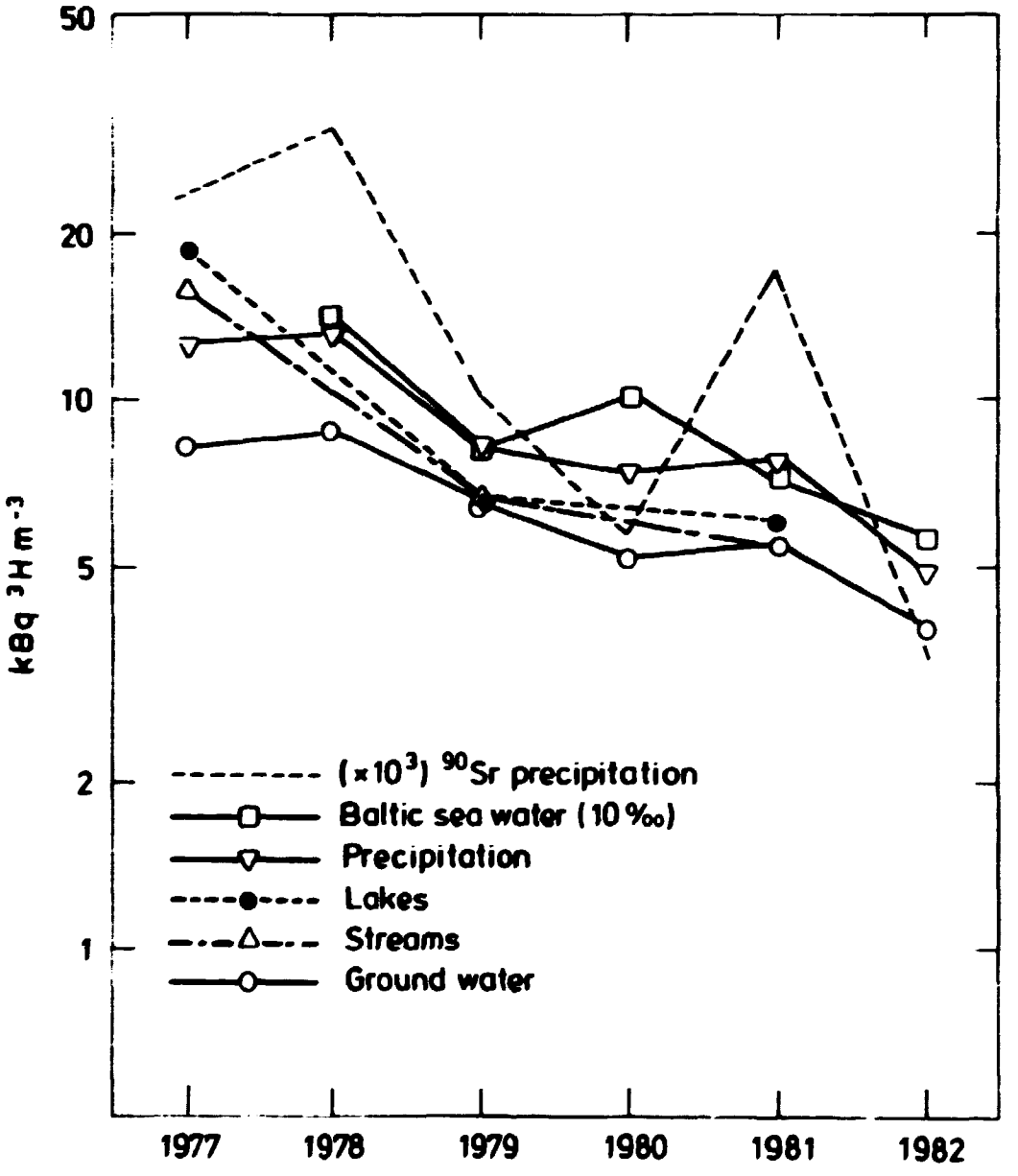


Fig. 7. Tritium in water samples collected in Denmark 1977-1982.

that stream and lake water for the most part consist of ground water and new precipitation. The Baltic sea water (salinity < 10 o/oo) is generally higher than stream water in tritium. This may be due to the long recidence time of water in the Baltic sea (~ 25 years), which means that a considerable part of the fresh water component in the Baltic water is old runoff from a time when the tritium concentrations were higher than those at present.

It is evident from the figure that the time variability of $^{90}Sr$ is more pronounced than that of tritium in precipitation. This is due to some recirculation From evaporation of older tritium fallout in the atmosphere, which smooths out the differences in the annual tritium concentrations (cf. also 4.2).

# 8. MEASUREMENTS OF BACKGROUND RADIATION IN 1982

by L. Bøtter-Jensen and S.P. Nielsen

## 8.1. Instrumentation

Measurements of the background radiation were made with thermoluminescence dosimeters (TLD's), a mobile Ge(Li) spectrometer system[24], a high-pressure ionization chamber (Reuter-Stokes RSS-111), and a NaI(Tl) detector.

## 8.2. State experimental farms

The State experimental farms are situated as shown in fig. 4.2. The results of the TLD measurements are shown in Table 8.2.1. The results of the NaI(Tl) detector measurements are shown in Table 8.2.2.

Table 8.2.1. TLD-measurements of the background radiation (integrated over 11 months and normalized to $\mu R\ h^{-1}$) at the State experimental farms in 1981/82

| | Oct 1981 - Sep 1982 $\mu R\ h^{-1}$ |
|---|---|
| Tylstrup | 7.4 |
| Borris | 7.0 |
| Ødum | 7.8 |
| Askov | 6.9 |
| St. Jyndevad | 6.1 |
| Blangstedgård | 6.9 |
| Tystofte | 8.3 |
| Abed | 8.2 |
| Mean | 7.3 |

Table 8.2.2. Terrestrial exposure rates at the State experimental farms measured with the NaI(Tl) detector in 1982 ($\mu R\ h^{-1}$)

| Location | March | June | Oct | Mean |
|---|---|---|---|---|
| Tylstrup | 3.1 | 3.2 | 3.2 | 3.2 |
| Borris | 3.8 | 4.1 | 4.1 | 4.0 |
| Ødum | 4.2 | 4.5 | 4.9 | 4.5 |
| Askov | 3.3 | 3.6 | 3.7 | 3.5 |
| St. Jyndevad | 1.9 | 2.2 | 2.2 | 2.1 |
| Blangstedgaard | 4.5 | 4.5 | 4.6 | 4.5 |
| Ledreborg | 4.8 | 5.1 | 5.2 | 5.0 |
| Tystofte | 4.9 | 5.3 | 5.4 | 5.2 |
| Abed | 5.2 | 5.2 | 5.3 | 5.2 |
| Tornbygård | (5.7) | 5.9 | (6.0) | 5.9 |
| Mean | 4.1 | 4.4 | 4.5 | 4.3 |

Figures in brackets calculated from VAR2[12].

The γ-background measured with the NaI(Tl) detector in four groups of sampling stations is shown in fig. 8.2.1 from 1962 to 1982. The change of levels in 1977 is due to a modification of the instrument and of the calculational procedure[31].

The results of ionization chamber measurements are shown in Table 8.2.3. Due to a malfunction of the apparatus the results from some of the experimental farms are missing. The results of Ge(Li) spectrometer measurements are shown in Tables 8.2.4 and 8.2.5.

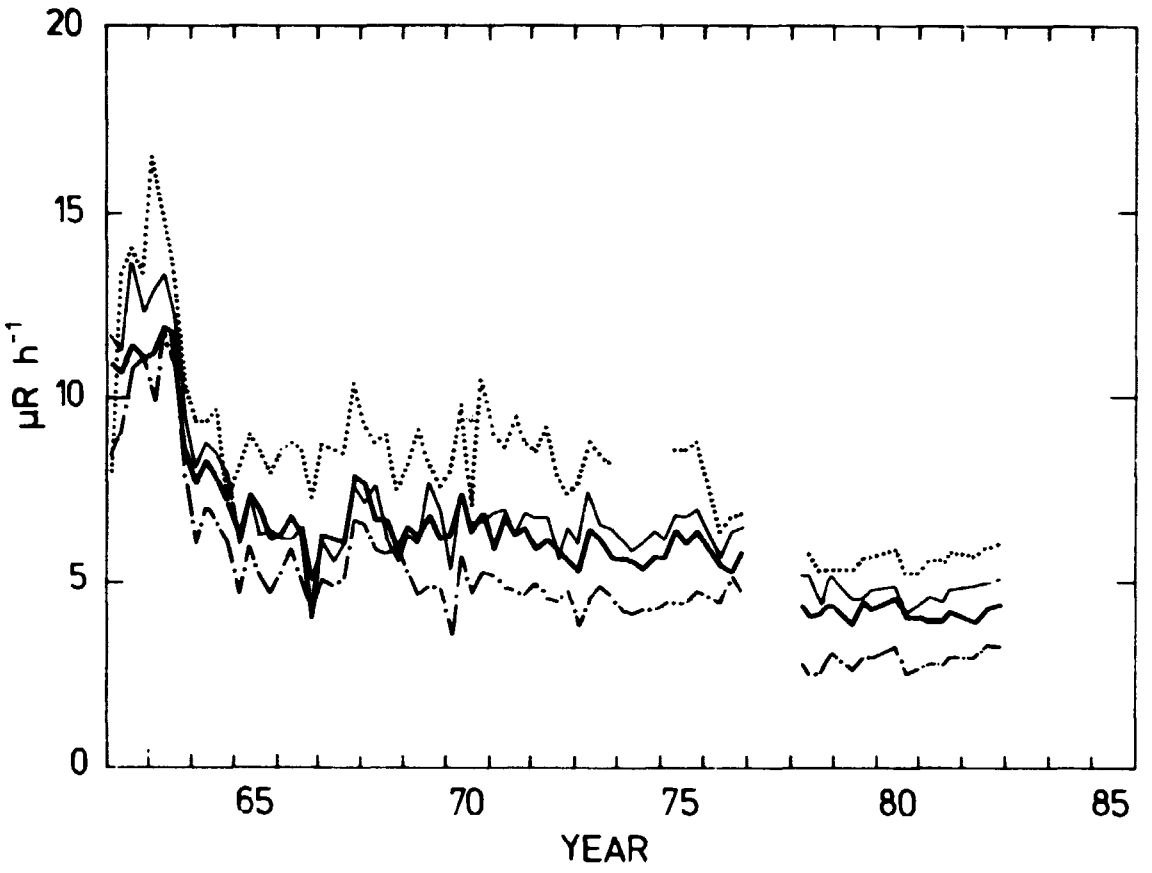


Fig. 8.2.1. Terrestrial exposure rates at the State experimental farms in 1962-1976 and 1978-1982 measured with the NaI(Tl) detector (μR $h^{-1}$).

..... Åkirkeby/Tornby Ård

——— Abed, Blangstedgård, Tystofte

▬▬▬ Virumgård/Ledreborg, Ødum, Tylstrup

—·— Jyndevad, Askov, Studsgård/Borris

Table 8.2.3. Ionization chamber measurements of the background radiation at the State experimental farms in September 1982 (μR $h^{-1}$)

| Location | September |
|---|---|
| Tystofte | 8.5 |
| Abed | 8.7 |
| Tornbygård | 9.5 |

Table 8.2.4. Terrestrial exposure rates at the State experimental farms estimated from field spectroscopic measurements made in September 1982 ($\mu R\ h^{-1}$)

| Location | $^{40}K$ | $^{226}Ra$ | $^{232}Th$ | $^{137}Cs$ | Total |
|---|---|---|---|---|---|
| Tylstrup | 1.7 | 0.6 | 0.8 | 0.1 | 3.2 |
| Borris | 1.4 | 0.6 | 0.9 | 0.1 | 3.0 |
| Ødum | 2.3 | 0.8 | 1.4 | 0.1 | 4.5 |
| Askov | 1.3 | 0.6 | 0.9 | 0.1 | 3.0 |
| St. Jyndevad | 1.0 | 0.3 | 0.4 | 0.2 | 1.9 |
| Blangstedgård | 2.1 | 0.8 | 1.4 | 0.1 | 4.4 |
| Ledreborg | 2.2 | 1.0 | 1.4 | 0.1 | 4.7 |
| Tystofte | 2.4 | 1.0 | 1.5 | 0.1 | 4.9 |
| Abed | 2.3 | 1.0 | 1.7 | 0.1 | 5.0 |
| Tornbygård | 2.7 | 1.1 | 1.9 | 0.1 | 5.9 |
| Mean | 1.9 | 0.8 | 1.2 | 0.1 | 4.1 |

Table 8.2.5. Concentrations of radionuclides in the soil at the State experimental farms estimated from field spectroscopic measurements made in September 1982. (Unit: $Bq\ kg^{-1}$)

| Location | $^{40}K$ | $^{226}Ra$ | $^{232}Th$ | $^{137}Cs$ |
|---|---|---|---|---|
| Tylstrup | 350 | 11.5 | 10.4 | 7.0 |
| Borris | 280 | 11.8 | 12.2 | 7.4 |
| Ødum | 460 | 15.9 | 17.8 | 4.8 |
| Askov | 270 | 11.5 | 12.2 | 8.1 |
| St. Jyndevad | 200 | < 6 | 5.6 | 11.5 |
| Blangstedgård | 420 | 16.3 | 18.9 | 5.2 |
| Ledreborg | 450 | 18.9 | 18.5 | 4.1 |
| Tystofte | 470 | 18.5 | 19.6 | 5.2 |
| Abed | 460 | 19.2 | 23 | 5.2 |
| Tornbygård | 550 | 22 | 26 | 4.8 |
| Mean | 390 | 15.1 | 16.4 | 6.3 |

## 8.3. Risø environment

The five zones around Risø are located as shown in fig. 8.3.1. The results of the TLD measurements are shown in Table 8.3.1, and the results of the NaI(Tl) detector measurements are shown in Table 8.3.2.

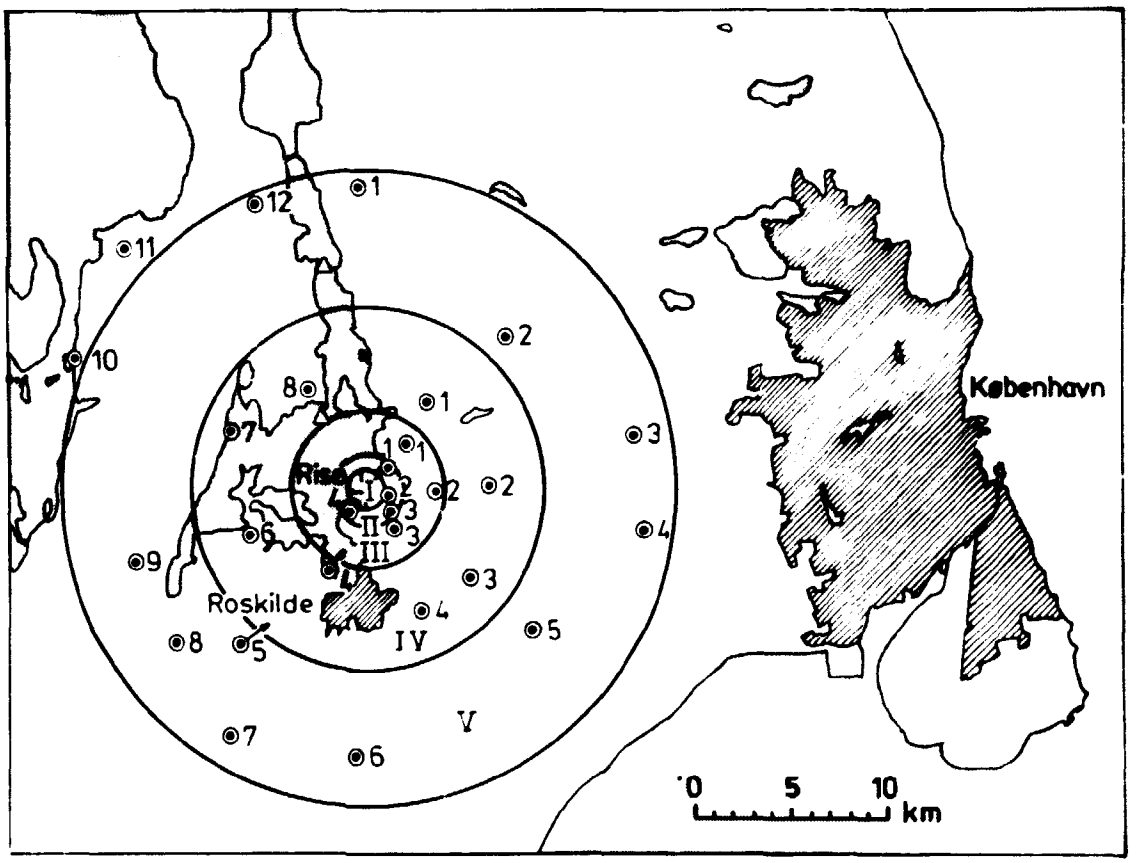


Fig. 8.3.1. The environment of Risø. Locations for measurements of the background radiation.

Table 8.3.1. TLD-measurements of the background radiation (mean of two 6-month integration periods and normalized to R $h^{-1}$) in five zones (I-V) around Risø in 1982

| Risø zone | Location | Oct 1981 - Feb 1983 R $h^{-1}$ |
|---|---|---|
| I | 1 | 8.0 |
| " | 2 | 8.8 |
| " | 3 | 19.8 |
| " | 4 | 8.7 |
| " | 5 | 11.1 |
| Mean | | 11.3 |
| II | 1 | 7.9 |
| " | 2 | 8.3 |
| " | 3 | 7.5 |
| " | 4 | 8.0 |
| Mean | | 7.9 |
| III | 1 | 8.6 |
| " | 2 | 8.2 |
| " | 3 | 8.6 |
| Mean | | 8.5 |
| IV | 1 | 7.5 |
| " | 2 | 8.0 |
| " | 3 | 8.0 |
| " | 4 | 9.0 |
| " | 5 | 6.6 |
| " | 6 | 8.0 |
| " | 7 | 8.5 |
| Mean | | 7.9 |
| V | 1 | 8.1 |
| " | 2 | 8.8 |
| " | 3 | 8.3 |
| " | 4 | 7.8 |
| " | 5 | 8.3 |
| " | 6 | 8.5 |
| " | 7 | 8.4 |
| " | 8 | 6.9 |
| " | 9 | 8.5 |
| " | 10 | 8.3 |
| Mean | | 8.2 |

Table 8.3.2. Terrestrial exposure rates at the Risø zones in 1982 measured with the NaI(Tl) detector (μR $h^{-1}$)

| Risø zone | Location | March | April | July | October |
|---|---|---|---|---|---|
| I | 1 | 3.8 | 4.1 | 5.2 | 5.3 |
| " | 2 | 5.? | 4.4 | 7.1 | 6.8 |
| " | 3 | 66.8 | 59.2 | 66.8 | 63.2 |
| " | 4 | 7.0 | 5.2 | 5.3 | 5.6 |
| " | 5 | 8.2 | 9.8 | 9.6 | 9.9 |
| Mean | | 18.2 | 16.5 | 18.8 | 18.2 |
| II | 1 | 4.7 | 4.4 | 3.7 | 4.5 |
| " | 2 | 5.1 | 5.0 | 4.7 | 5.1 |
| " | 3 | 4.8 | 4.9 | 4.8 | 4.8 |
| " | 4 | 4.8 | 4.3 | 4.4 | 4.3 |
| Mean | | 4.8 | 4.6 | 4.4 | 4.7 |
| III | 1 | | 5.1 | | 5.2 |
| " | 2 | | 4.9 | | 4.8 |
| " | 3 | | 4.5 | | 4.4 |
| Mean | | | 4.8 | | 4.8 |
| IV | 1 | | 4.4 | | 4.5 |
| " | 2 | | 4.2 | | 4.2 |
| " | 3 | | 4.8 | | 4.8 |
| " | 4 | | 4.3 | | 4.2 |
| " | 5 | | 2.6 | | 2.6 |
| " | 6 | | 3.9 | | 3.8 |
| " | 7 | | 4.3 | | 4.4 |
| Mean | | | 4.1 | | 4.1 |
| V | 1 | | 4.9 | | 4.8 |
| " | 2 | | 5.0 | | 5.0 |
| " | 3 | | 4.0 | | 3.9 |
| " | 4 | | 3.9 | | 4.0 |
| " | 5 | | 4.2 | | 4.0 |
| " | 6 | | 4.6 | | 4.7 |
| " | 7 | | 4.7 | | 4.6 |
| " | 8 | | 4.1 | | 4.2 |
| " | 9 | | 4.2 | | 4.2 |
| " | 10 | | 3.2 | | 3.2 |
| Mean | | | 4.3 | | 4.3 |

## 8.4. Gylling Næs environment

The Gylling Næs environment (a potential nuclear power plant site) is routinely monitored with TLD's, and the results from the site are given in Table 8.4.1. The locations are shown in Fig. 8.4.1.

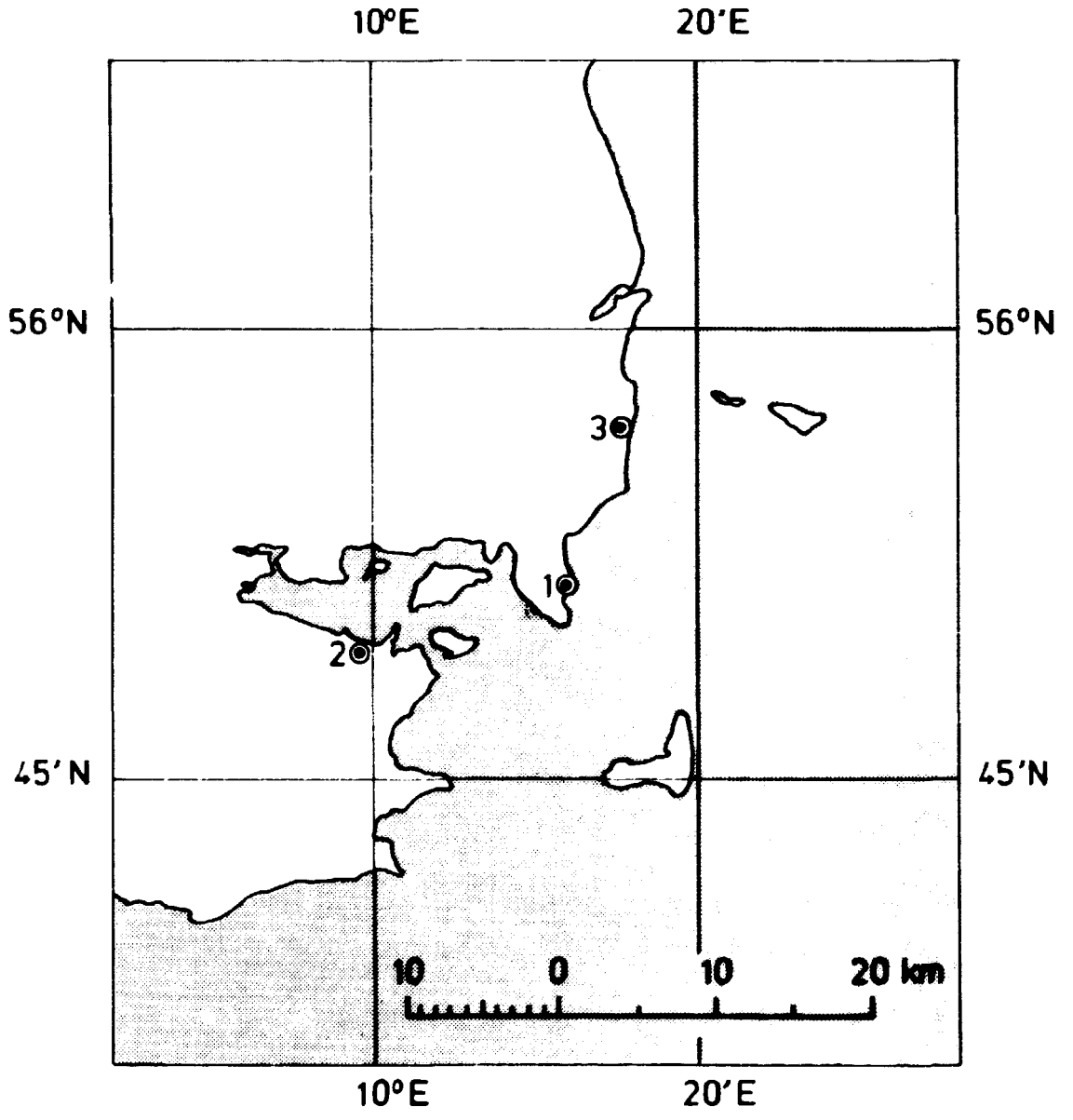


Fig. 8.4.1. The environment of Gylling Næs. Locations for measurements of the background radiation.

Table 8.4.1. TLD-measurements of the background radiation (integrated over 11 months and normalized to $\mu R\ h^{-1}$) around the Gyllingnæs site in 1981/82

| Location | Oct 1981 - Sep 1982 $\mu R\ h^{-1}$ |
|---|---|
| 1 | 7.7 |
| 2 | 8.1 |
| 3 | 7.9 |
| Mean | 7.9 |

## 8.5. Great Belt and Langeland Belt areas

Locations on both shores of the Great Belt and the Langeland Belt (an international shipping route) are likewise routinely monitored with TLD's; the results and locations are shown in Table 8.5.1 and Fig. 8.5.1, respectively.

Table 8.5.1. TLD-measurements of the background radiation (integrated over 11 months and normalized to $\mu R\ h^{-1}$) along the coasts of the Great Belt and Langeland Belt in 1981/82

| Location | Oct 1981 - Sep 1982 $\mu R\ h^{-1}$ |
|---|---|
| Rønnæs | 7.5 |
| Reersø | 8.1 |
| Svendstrup | 7.5 |
| Frederiksdal | 8.8 |
| Kelds Nor | 8.9 |
| Tranekær | 8.7 |
| Hov | - |
| Pyns Hoved | 7.9 |
| Knuds Hoved | 8.4 |
| Mean | 8.2 |

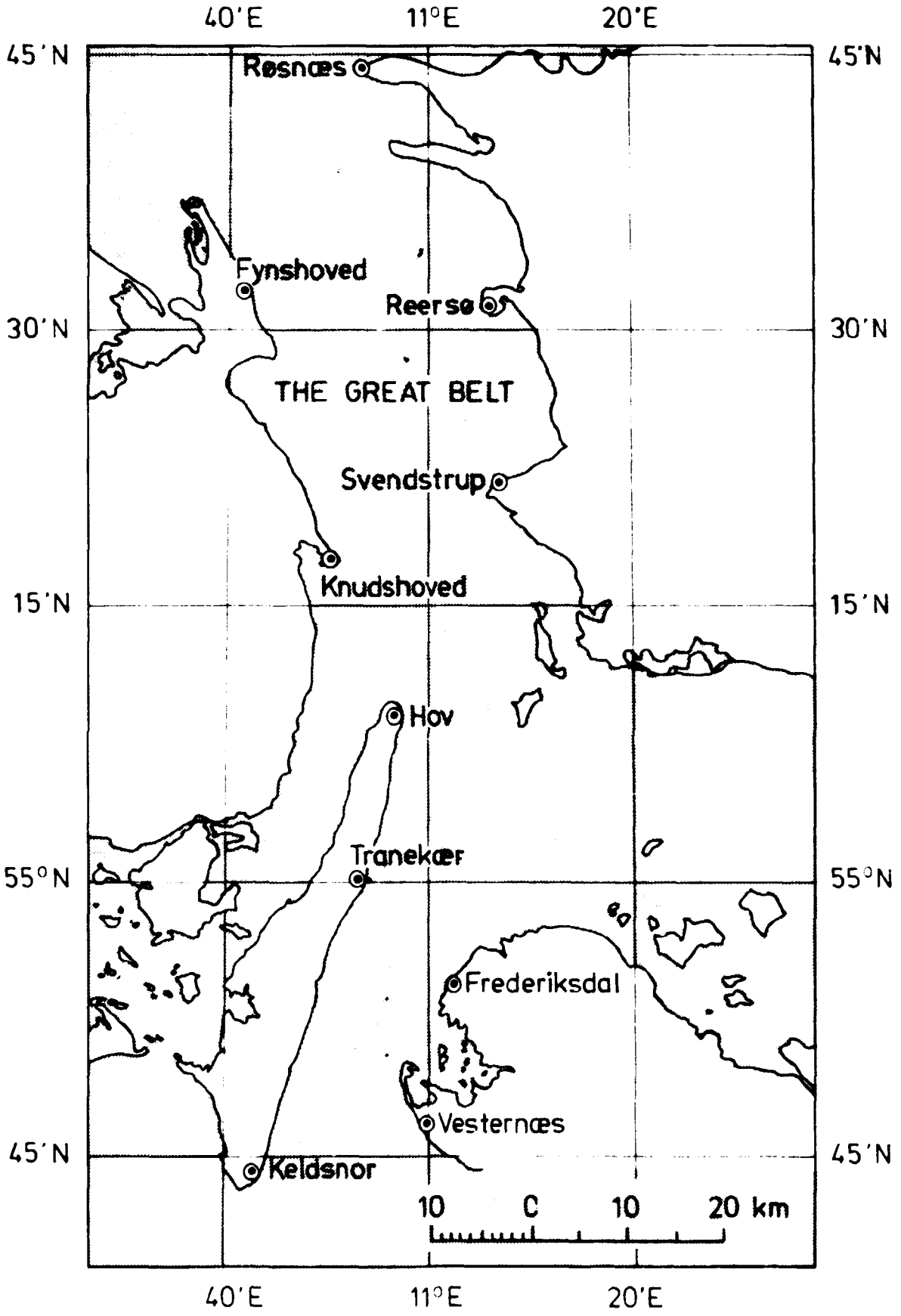


Fig. 8.5.1. The coasts of the Great Belt. Locations for measurements of the background radiation.

## 8.6. The Baltic island, Bornholm

Locations on the island of Bornholm have been monitored with TLD's in the period June 1981-May 1982. The results and locations are shown in Table 8.6.1 and Fig. 8.6.1, respectively.

Table 8.6.1. TLD-measurements of the background radiation (integrated over 11 months and normalized to $\mu R\ h^{-1}$) on the island Bornholm in 1981/82

| Location | June 1981 - May 1982 $\mu R\ h^{-1}$ |
|---|---|
| 1 | 9.1 |
| 2 | 9.5 |
| 3 | 8.7 |
| 4 | 15.3 |
| Mean | 10.6 |

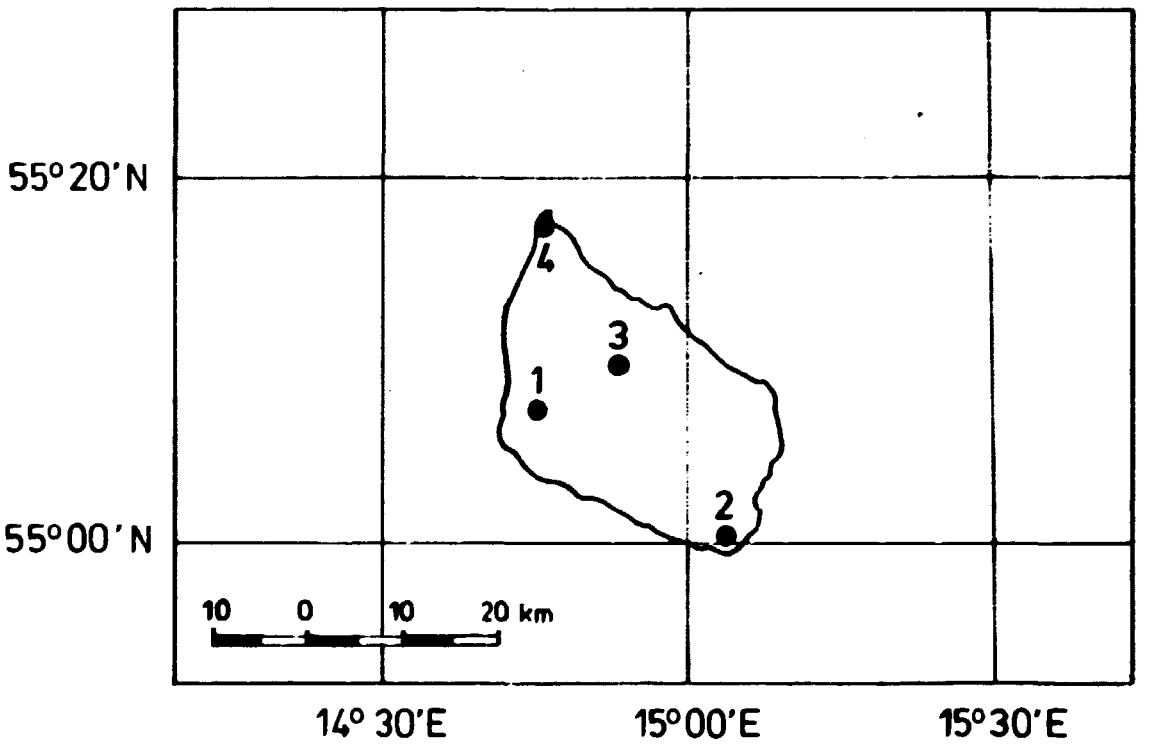


Fig. 8.6.1. Locations for measurements on Bornholm.

## 8.7. Discussion

The reported results are in reasonable agreement with those obtained in 1981.

# 9. CONCLUSION

## 9.1. Environmental monitoring at Risø, Barsebäck and Ringhals

No radioactive contamination of the environment originating from the operation of the National Laboratory was ascertained outside Risø in 1982.

Benthic brown algae, mussels and fish collected at the Swedish nuclear plants at Barsebäck and Ringhals were analysed for radioactive pollution. Transfer factors from releases of various radionuclides to Fucus were calculated. The radioactive contamination of the marine environment due to the operation of the Swedish nuclear power plants resulted into doses of less than 1% of the background radiation to any individual eating 20 kg mussel and 100 kg fish per year.

## 9.2. Nuclear-weapon debris in the abiotic environment

The mean content of $^{90}Sr$ in air collected in 1982 was 7 μBq $m^{-3}$ (0.18 fCi $^{90}Sr$ $m^{-3}$), i.e. approximately 25% of the 1981 level. The average fallout at the State experimental farms in 1982 was 2 Bq $^{90}Sr$ $m^{-2}$ (0.056 mCi $^{90}Sr$ $km^{-2}$) or 16% of the 1981 figure, and the mean concentration of $^{90}Sr$ in rain water was 3.4 Bq $^{90}Sr$ $m^{-3}$ (0.093 pCi $^{90}Sr$ $l^{-1}$).

By the end of 1982 the accumulated fallout was approximately 1680 Bq $^{90}Sr$ $m^{-2}$ (45 mCi $^{90}Sr$ $km^{-2}$). The corresponding $^{137}Cs$ was estimated at 2690 Bq $m^{-2}$.

The median level of $^{90}Sr$ in Danish ground water was 0.06 Bq $m^{-3}$ (1.6 fCi $^{90}Sr$ $l^{-1}$). Drinking water showed a median level of 0.21 Bq $^{90}Sr$ $m^{-3}$.

Inner Danish surface waters (salinity ~ 16 o/oo) contained 24 Bq $^{90}Sr\ m^{-3}$ (0.6 pCi $^{90}Sr\ l^{-1}$) and 37 Bq $^{137}Cs\ m^{-3}$ (1.0 pCi $^{137}Cs\ l^{-1}$).

## 9.3. Fallout nuclides in the human diet

The mean level of $^{90}Sr$ in Danish milk was 102 Bq $(kg\ Ca)^{-1}$ (2.8 S.U.), and the mean content of $^{137}Cs$ was approximately 105 Bq $m^{-3}$ (2.8 pCi $^{137}Cs\ l^{-1}$).

The 1982 $^{90}Sr$ and $^{137}Cs$ levels were 1.0 and 0.8 times respectively the levels found in milk produced in 1981.

The $^{90}Sr$ mean content in grain from the 1982 harvest was 0.58 Bq $kg^{-1}$ (16 pCi $^{90}Sr\ kg^{-1}$). The $^{137}Cs$ mean content in grain was 0.12 Bq $kg^{-1}$ (3.3 pCi $^{137}Cs\ kg^{-1}$). The $^{90}Sr$ level in grain from the 1982 harvest was 0.6 times the level found in the 1981 harvest, and $^{137}Cs$ was 0.14 times the 1981 level.

The mean contents of $^{90}Sr$ and $^{137}Cs$ in Danish vegetables collected in 1982 were 0.32 Bq $^{90}Sr\ kg^{-1}$ (8.6 pCi $kg^{-1}$) and 0.05 Bq $^{137}Cs\ kg^{-1}$ (1.4 pCi $kg^{-1}$), respectively, and in fruit 0.023 Bq $^{90}Sr\ kg^{-1}$ (0.6 pCi $kg^{-1}$) and 0.044 Bq $^{137}Cs\ kg^{-1}$ (1.2 pCi $kg^{-1}$); potatoes contained 0.065 Bq $^{90}Sr\ kg^{-1}$ (1.8 pCi $kg^{-1}$) and 0.063 Bq $^{137}Cs\ kg^{-1}$ (1.7 pCi $kg^{-1}$).

The mean levels of $^{90}Sr$ and $^{137}Cs$ in total-diet samples collected in 1982 were 152 Bq $^{90}Sr\ (kg\ Ca)^{-1}$ (4.1 S.U.) and 106 Bq $^{137}Cs\ (kg\ K)^{-1}$ (2.9 M.U.), respectively. From analyses of the individual diet components, the $^{90}Sr$ level in the Danish average diet was estimated to be 151 Bq $^{90}Sr\ (kg\ Ca)^{-1}$ (4.1 S.U.) and the $^{137}Cs$ level to be 112 Bq $^{137}Cs\ (kg\ K)^{-1}$ (3.0 M.U.). The levels of $^{90}Sr$ and $^{137}Cs$ in the Danish total diet consumed in 1982 were nearly equal to the levels observed in 1981.

Grain products contributed 40% and milk products 30% to the total $^{90}Sr$ intake; 30% of the $^{137}Cs$ in the diet originated from grain products, 14% from meat, and 12% from milk products. Fish contributed with 30% to the $^{137}Cs$ diet intake, of this 90% were estimated to be due to radiocesium from Sellafield (Windscale).

Both $^{90}Sr$ and $^{137}Cs$ diet levels were on the average higher in Jutland than in eastern Denmark.

## 9.4. Strontium-90 and Cesium-137 in humans

The $^{90}Sr$ mean content in human bone (vertebrae) collected in 1982 was about 34 Bq (kg Ca)$^{-1}$ (0.9 S.U.).

Whole-body measurements of $^{137}Cs$ have been suspended due to the low $^{137}Cs$ concentrations in man. The estimated level in 1982 was 279 Bq $^{137}Cs$ (kg K)$^{-1}$ (7.5 pCi $^{137}Cs$ (g K)$^{-1}$).

## 9.5. Tritium in environmental samples

The tritium concentration in ground water was approximately 4 kBq m$^{-3}$ in 1982. The mean content of precipitation was nearly the same and Baltic sea water (10 o/oo salinity) contained 5.5 kBq $^{3}H$ m$^{-3}$.

## 9.6. Background radiation

The average total background exposure rate measured with TLD's at the State experimental farms was 7.3 µR h$^{-1}$. The average terrestrial background exposure rate measured with a NaI(Tl) detector at the State experimental farms was 4.3 µR h$^{-1}$. These results are in accordance with those observed in 1981.

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We are specially indebted to the staffs of the ten State experimental farms at Tylstrup, Ødum, Borris, Askov, St. Jyndevad, Blangstedgård, Tystofte, Ledreborg, Abed, and Åkirkeby, who have continued to supply us with a number of the most important samples dealt with in this report.

R/V DANA belonging to the Ministry of Fisheries have collected surface water samples from the North Sea, the Danish Straits and the Baltic Sea in 1982.

HMS Fylla and M/S Nella Dan have collected surface sea water samples from the North Atlantic in 1982 and we convey our thanks to these ships for their whole-hearted cooperation.

Appendix A. Calculated fallout in Denmark in 1982

| Zone | mm precipitation in 1982 | Bq $^{90}Sr$ $m^{-2}$ in 1982 | Accumulated Bq $^{90}Sr$ $m^{-2}$ by the end of 1982 |
|---|---|---|---|
| I: N. Jutland<br>II: E. Jutland<br>III: W. Jutland<br>IV: S. Jutland | 778<br>(791) | 2.2 | 1872 |
| V: Funen<br>VI: Zealand<br>VII: Lolland-Falster | 596<br>(618) | 1.7 | 1494 |
| VIII: Bornholm | 569<br>(579) | 2.9 | - |
| Area-weighted mean | 721<br>(737) | 2.1 | 1759 |

The amounts of precipitation were obtained from ref. 9. The $^{90}Sr$ deposition was estimated from 4.2 and appendix D.

The precipitations in brackets were the mean of values measured by the Meteorological Institute at the State experimental farms:
Jutland: Tylstrup, Ødum, Borris, Askov, St. Jyndevad;
The Islands: Blangstedgård, Tystofte, Ledreborg, Abed;
Bornholm: Åkirkeby.

Appendix B. Statistical information

| Zone | | Area in $km^2$ 15) 1971 | Population in thousands 28) 1976 | Annual milk production in mega-kg 14) 1971 | Annual wheat production in mega-kg 13) 1972 | Annual rye production in mega-kg 13) 1972 | Annual potato production in mega-kg 13) 1972 | Vegetable area in $km^2$ 13) 1972 |
|---|---|---|---|---|---|---|---|---|
| I: | N. Jutland | 6,171 | 471 | 911 | | | | |
| II: | E. Jutland | 7,561 | 881 | 1,258 | 145 | 155 | 609 | 14 |
| III: | W. Jutland | 12,104 | 687 | 926 | | | | |
| IV: | S. Jutland | 3,929 | 245 | 572 | | | | |
| V: | Funen | 3,486 | 446 | 393 | | | | |
| VI: | Zealand | 7,435 | 2,165* | 395 | | | | |
| VII: | Lolland-Falster | 1,795 | 123 | 68 | 448 | 71 | 100 | 73 |
| VIII: | Bornholm | 588 | 47 | 39 | | | | |
| Total | | 43,069 | 5,065 | 4,562 | 593 | 226 | 709 | 87 |

*1,270,000 people were living in Greater Copenhagen and 895,000 in the remaining part of Zealand.

APPENDIX C

For the calculation of the $^{137}Cs$ levels we have assumed the $^{137}Cs/^{90}Sr$ ratio equal to 1.6 because that was the ratio used in reference 21. This may as is suggested from Tables 4.2.4 and 4.2.5 have overestimated the $^{137}Cs$ deposition in 1982, on the other hand, it may have underestimated it for the previous years[1].

Appendix C.1. Comparison between observed and predicted $^{90}Sr$ levels in environmental samples collected in 1982

| Sample | Location | Unit | Observed | Predicted | Obs./pred. | Model in reference (21) |
|---|---|---|---|---|---|---|
| Dried milk* | Jutland | Bq $^{90}Sr$ (kg Ca)$^{-1}$ | 124 | 118 | 1.05 | C.3.2.1 No. 1 |
| " " | Islands | - " - | 79 | 43 | 1.84 | - " - No. 3 |
| Rye | Jutland | Bq $^{90}Sr$ kg$^{-1}$ | 0.75 | 0.46 | 1.63 | C.2.2.1 No. 1 |
| " | Islands | - " - | 0.57 | 0.126 | 4.52 | - " - No. 3 |
| Barley | Jutland | - " - | 0.73 | 0.66 | 1.11 | - " - No. 4 |
| " | Islands | - " - | 0.42 | 0.28 | 1.50 | - " - No. 6 |
| Wheat | Jutland | - " - | 0.52 | 0.61 | 0.85 | - " - No. 8 |
| " | Islands | - " - | 0.56 | 0.26 | 2.15 | - " - No. 10 |
| Oats | Jutland | - " - | 0.80 | 1.44 | 0.56 | - " - No. 12 |
| " | Islands | - " - | 0.52 | 0.67 | 0.78 | - " - No. 13 |
| Rye bread | Denmark | - " - | 0.57 | 0.50 | 1.14 | C.2.3.1 No. 1 |
| White bread | " | - " - | 0.23 | 0.14 | 1.64 | - " - No. 2 |
| Potatoes | Jutland | - " - | 0.070 | 0.107 | 0.65 | C.2.5.1 No. 8 |
| " | Islands | - " - | 0.061 | 0.096 | 0.64 | - " - No. 10 |
| Cabbage | Jutland | - " - | 0.46 | 0.34 | 1.35 | - " - No. 1 |
| " | Islands | - " - | 0.24 | 0.29 | 0.83 | - " - No. 3 |
| Carrot | Jutland | - " - | 0.55 | 0.58 | 0.95 | - " - No. 5 |
| " | Islands | - " - | 0.33 | 0.21 | 1.57 | - " - No. 6 |
| Apples | Denmark | - " - | 0.023 | 0.015 | 1.53 | C.2.5.1 No. 13 |
| Pork* | " | - " - | 0.017 | 0.027 | 0.63 | C.3.4.1 No. 3 |
| Beef* | " | - " - | 0.055 | 0.037 | 1.49 | - " - No. 1 |
| Eggs | " | - " - | 0.030 | 0.014 | 2.14 | C.3.6.1 No. 6 |
| Total diet C | " | Bq $^{90}Sr$ (kg Ca)$^{-1}$ | 152 | 170 | 0.89 | C.4.2.1 No. 1 |
| " " P | " | - " - | 151 | 146 | 1.03 | - " - No. 7 |
| Human bone > 29 yr | " | - " - | 34 | 42 | 0.81 | C.4.3.1 No. 13 |
| Whole year grass | Islands | - " - | 720 | 570 | 1.26 | C.2.4.1 No. 1 |
| Fucus vesiculosus | " | - " - | 400 | 470 | 0.85 | C.2.7.1 No. 3 |
| Zostera marina | " | - " - | 90 | 83 | 1.08 | - " - No. 1 |
| Ground water | Denmark | Bq $^{90}Sr$ m$^{-3}$ | 0.32 | 0.32 | 1.00 | C.1.4.1 No. 1 |
| Grass | Zealand | Bq $^{90}Sr$ (kg Ca)$^{-1}$ | 725 | 570 | 1.27 | C.2.4.1 No. 1 |

*May 1982 - April 1983 ("milk year" (21)).

Appendix C.2. Comparison between observed and predicted $^{137}Cs$ levels in environmental samples collected in 1982

| Sample | Location | Unit | Observed | Predicted | Obs./pred. | Model in reference (21) |
|---|---|---|---|---|---|---|
| Dried milk* | Jutland | Bq $^{137}Cs$ $(kg\ K)^{-1}$ | 83 | 43 | 1.70 | C.3.2.2 No. 1 |
| " " | Islands | - " - | 32 | 36 | 0.89 | - " - No. 3 |
| Rye | Jutland | Bq $^{137}Cs$ $kg^{-1}$ | 0.189 | 0.148 | 1.28 | C.2.2.4 No. 2 |
| " | Islands | - " - | 0.163 | 0.115 | 1.42 | - " - No. 3 |
| Barley | Jutland | - " - | 0.133 | 0.108 | 1.23 | - " - No. 4 |
| " | Islands | - " - | 0.079 | 0.078 | 1.01 | - " - No. 5 |
| Wheat | Jutland | - " - | 0.127 | 0.109 | 1.16 | - " - No. 6 |
| " | Islands | - " - | 0.077 | 0.067 | 1.15 | - " - No. 7 |
| Oats | Jutland | - " - | 0.130 | 0.089 | 1.46 | - " - No. 8 |
| " | Islands | - " - | 0.080 | 0.073 | 1.10 | - " - No. 9 |
| Rye bread | Denmark | - " - | 0.73 | 0.70 | 1.04 | C.2.3.1 No. 4 |
| White bread | " | - " - | 0.172 | 0.170 | 1.01 | - " - No. 5 |
| Potatoes | Jutland | - " - | 0.106 | 0.132 | 0.80 | C.2.5.3 No. 5 |
| " | Islands | - " - | 0.019 | 0.0104 | 1.83 | - " - No. 7 |
| Cabbage | Denmark | - " - | 0.028 | 0.039 | 0.72 | - " - No. 1 |
| Carrot | " | - " - | 0.038 | 0.012 | 3.17 | - " - No. 3 |
| Apples | " | - " - | 0.044 | 0.037 | 1.19 | C.2.5.3 No. 11 |
| Pork* | " | - " - | 0.31 | 0.41 | 0.76 | C.3.4.2 No. 3 |
| Beef* | " | - " - | 0.40 | 0.14 | 2.86 | - " - No. 1 |
| Eggs | " | - " - | 0.033 | 0.053 | 0.62 | C.3.6.2 No. 6 |
| Total diet C | " | Bq $^{137}Cs$ $(kg\ K)^{-1}$ | 77 | 49 | 1.57 | C.4.2.2 No. 1 |
| " " P | " | - " - | 82** | 87 | 0.94 | - " - No. 6 |

* (cf. note to Appendix C.1)

**Exclusive contribution of $^{137}Cs$ from Sellafield. (27% Sellafield, 73% fallout)

## APPENDIX D

$\underline{d_i}$:

Annual fallout rate in mCi $^{90}Sr$ $km^{-2}$ $y^{-1}$.

Accumulated fallout by the end of the year (i) assuming effective half-lives of $^{90}Sr$ of 27.7 y. Unit: mCi $^{90}Sr$ $km^{-2}$.

$\underline{d_{i(May-Aug)} \text{ and } d_{i(July-Aug)}}$:

The fallout rates in the periods: May-Aug and July-Aug, respectively. Unit: mCi $^{90}Sr$ $km^{-2}$ $period^{-1}$.

The fallout rate ($d_i$) was based on precipitation data collected for all Denmark in the period 1962-1982 (cf. Table 4.2.1[1]). Before 1962 the levels in the tables were estimated from the HASL data for New York (HASL Appendix 291, 1975)[29] considering that the mean ratio between $^{90}Sr$ fallout in Denmark and New York was 0.7 in the period 1962-1974.

The $d_{i(May-Aug)}$ and $d_{i(July-Aug)}$ values were also obtained from Table 4.2.1[1] for the period 1962-1982. For the years 1959-1961 the values were calculated from data obtained from $^{90}Sr$ analysis of air (1959) and precipitation samples (1962 and 1961) collected at Risø. Before 1959, the values were estimated from the corresponding $d_i$ values assuming that the ratios $d_{i(May-Aug)}/d_i$ and $d_{i(July-Aug)}/d_i$ were constant in time and equal to the means found for the period 1962-1974, which were 0.54 (1 S.D.: 0.09) and 0.24 (1 S.D.: 0.06), respectively.

Appendix D. Fallout rates and accumulated fallout (mCi $^{90}Sr$ $km^{-2}$) in Denmark 1950-1982

| | Denmark | | Jutland | | Islands | |
|---|---|---|---|---|---|---|
| | di | $Ai_{(27.7)}$ | di | $Ai_{(27.7)}$ | di | $Ai_{(27.7)}$ |
| 1950 | 0.021 | 0.020 | 0.022 | 0.021 | 0.020 | 0.020 |
| 1951 | 0.101 | 0.118 | 0.114 | 0.132 | 0.088 | 0.105 |
| 1952 | 0.198 | 0.309 | 0.224 | 0.347 | 0.172 | 0.270 |
| 1953 | 0.500 | 0.789 | 0.566 | 0.891 | 0.434 | 0.687 |
| 1954 | 1.901 | 2.623 | 2.152 | 2.967 | 1.650 | 2.279 |
| 1955 | 2.501 | 4.997 | 2.831 | 5.655 | 2.171 | 4.340 |
| 1956 | 3.101 | 7.898 | 3.510 | 8.939 | 2.692 | 6.858 |
| 1957 | 3.101 | 10.728 | 3.510 | 12.142 | 2.692 | 9.313 |
| 1958 | 4.302 | 14.658 | 4.869 | 16.591 | 3.734 | 12.725 |
| 1959 | 6.102 | 20.247 | 6.908 | 22.918 | 5.297 | 17.576 |
| 1960 | 1.140 | 20.859 | 1.291 | 23.610 | 0.990 | 18.107 |
| 1961 | 1.481 | 21.787 | 1.676 | 24.661 | 1.285 | 18.913 |
| 1962 | 7.428 | 28.493 | 7.976 | 31.830 | 6.880 | 25.155 |
| 1963 | 16.695 | 44.071 | 18.453 | 49.041 | 14.937 | 39.101 |
| 1964 | 10.412 | 53.136 | 11.685 | 59.225 | 9.139 | 47.048 |
| 1965 | 3.954 | 55.679 | 4.204 | 61.861 | 3.704 | 49.497 |
| 1966 | 2.145 | 56.395 | 2.166 | 62.445 | 2.124 | 50.345 |
| 1967 | 1.047 | 56.023 | 1.176 | 62.048 | 0.918 | 49.997 |
| 1968 | 1.403 | 56.006 | 1.568 | 62.045 | 1.237 | 49.968 |
| 1969 | 1.035 | 55.632 | 1.241 | 61.721 | 0.829 | 49.542 |
| 1970 | 1.647 | 55.863 | 1.993 | 62.140 | 1.301 | 49.586 |
| 1971 | 1.506 | 55.951 | 1.726 | 62.288 | 1.286 | 49.615 |
| 1972 | 0.435 | 54.993 | 0.457 | 61.194 | 0.413 | 48.792 |
| 1973 | 0.192 | 53.821 | 0.215 | 59.891 | 0.168 | 47.750 |
| 1974 | 0.710 | 53.183 | 0.779 | 59.171 | 0.643 | 47.197 |
| 1975 | 0.414 | 52.272 | 0.452 | 58.150 | 0.376 | 46.397 |
| 1976 | 0.103 | 51.082 | 0.116 | 56.826 | 0.090 | 45.339 |
| 1977 | 0.384 | 50.204 | 0.405 | 55.827 | 0.362 | 44.581 |
| 1978 | 0.463 | 49.426 | 0.538 | 54.985 | 0.388 | 43.867 |
| 1979 | 0.166 | 48.379 | 0.174 | 53.810 | 0.156 | 42.947 |
| 1980 | 0.116 | 47.307 | 0.140 | 52.628 | 0.095 | 41.988 |
| 1981 | 0.353 | 46.482 | 0.379 | 51.697 | 0.330 | 41.272 |
| 1982 | 0.056 | 45.388 | 0.059 | 50.477 | 0.053 | 40.304 |

| Denmark | | Jutland | | Islands | |
|---|---|---|---|---|---|
| $d_i$ | $d_i$ | $d_i$ | $d_i$ | $d_i$ | $d_i$ (July-Aug) |
| 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| 0.05 | 0.02 | 0.06 | 0.03 | 0.05 | 0.02 |
| 0.11 | 0.05 | 0.12 | 0.05 | 0.09 | 0.04 |
| 0.27 | 0.12 | 0.31 | 0.14 | 0.23 | 0.10 |
| 1.03 | 0.46 | 1.16 | 0.52 | 0.89 | 0.40 |
| 1.35 | 0.60 | 1.53 | 0.68 | 1.17 | 0.52 |
| 1.67 | 0.74 | 1.90 | 0.84 | 1.45 | 0.65 |
| 1.67 | 0.74 | 1.90 | 0.84 | 1.45 | 0.65 |
| 2.32 | 1.03 | 2.63 | 1.17 | 2.02 | 0.90 |
| 2.50 | 0.68 | 2.76 | 0.75 | 2.24 | 0.61 |
| 0.47 | 0.31 | 0.52 | 0.34 | 0.42 | 0.28 |
| 0.66 | 0.47 | 0.73 | 0.52 | 0.59 | 0.42 |
| 4.223 | 1.857 | 4.566 | 2.052 | 3.880 | 1.662 |
| 9.965 | 5.629 | 10.753 | 5.932 | 9.177 | 5.327 |
| 6.235 | 2.568 | 7.170 | 2.910 | 5.299 | 2.226 |
| 2.029 | 0.850 | 2.094 | 0.852 | 1.964 | 0.848 |
| 1.049 | 0.418 | 0.984 | 0.496 | 1.114 | 0.340 |
| 0.367 | 0.141 | 0.380 | 0.134 | 0.354 | 0.148 |
| 0.848 | 0.426 | 0.910 | 0.460 | 0.786 | 0.392 |
| 0.614 | 0.276 | 0.723 | 0.319 | 0.505 | 0.233 |
| 0.908 | 0.547 | 1.076 | 0.632 | 0.740 | 0.462 |
| 0.992 | 0.405 | 1.154 | 0.516 | 0.830 | 0.294 |
| 0.253 | 0.084 | 0.262 | 0.094 | 0.244 | 0.084 |
| 0.075 | 0.033 | 0.093 | 0.039 | 0.057 | 0.027 |
| 0.421 | 0.190 | 0.463 | 0.219 | 0.378 | 0.162 |
| 0.159 | 0.075 | 0.179 | 0.091 | 0.157 | 0.060 |
| 0.032 | 0.010 | 0.032 | 0.011 | 0.032 | 0.009 |
| 0.178 | 0.107 | 0.164 | 0.085 | 0.190 | 0.129 |
| 0.232 | 0.096 | 0.275 | 0.098 | 0.188 | 0.093 |
| 0.086 | 0.030 | 0.087 | 0.031 | 0.084 | 0.029 |
| 0.063 | 0.027 | 0.079 | 0.031 | 0.047 | 0.022 |
| 0.214 | 0.073 | 0.215 | 0.071 | 0.213 | 0.075 |
| 0.027 | 0.0087 | 0.029 | 0.0104 | 0.025 | 0.0071 |

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